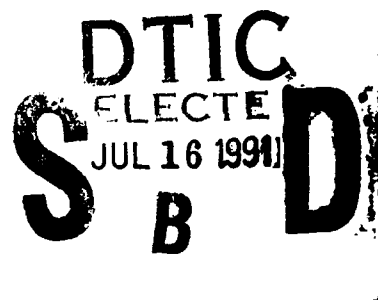


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THESIS

ANALYSIS OF SETUP TIME REDUCTIONS AT NADEP,
NORTH ISLAND UTILIZING THE SMED APPROACH
(SINGLE-MINUTE-EXCHANGE-OF-DIE)

by

Michael L. Combs

June, 1990

Thesis Advisor:

Dan Trietsch

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NORTH ISLAND, UTILIZING THE SMED APPROACH
(SINGLE-MINUTE-EXCHANGE-OF-DIE)

by

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Submitted in partial fulfillment
of the requirements for the degree of

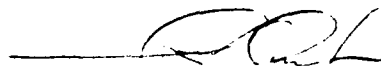
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ABSTRACT

This thesis is an analysis of setup time considerations currently employed by the Power Plant Facility at the Naval Aviation Depot, North Island. The system is analyzed within a production context, citing present procedures that adversely affect lead time. To reduce lead time variability, reduction of setup times is targeted. This thesis examines the potential benefits available to the Power Plant Facility by applying Single-Minute-Exchange-of-Die (SMED) to reduce setup times. SMED's conceptual stages are first examined and then related to the Power Plant Facility to illustrate the applicability of SMED to a repair/rebuild environment. Recommendations are made to reduce setup times in two work centers.

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I. INTRODUCTION

A. BACKGROUND

This thesis will examine the potential benefits available to the Power Plant Facility at the Naval Aviation Depot, North Island, by applying Single-Minute-Exchange-of-Die (SMED) to reduce setup times. SMED is an innovative thought process focused upon reducing setup times at work stations to less than 10 minutes. The method has successfully reduced many setups that once took hours to two or three minutes, creating a revolution of new thought and practices within industry today. [Ref. 1:p. xiv]

With SMED, setup times are no longer considered a constant aspect of lead time. While embracing a concept of continuous improvement, SMED involves change within an organization. Acceptance must be universal within an organization, commencing with top management. The positive effects upon cost savings and productivity are limitless when the organization accepts SMED as a thought process to reduce total lead times.

In an environment of decreasing DOD budget dollars, where service commitments are expected to remain constant or increase, managers must challenge and streamline current operating procedures. At the Naval Aviation Depot, North Island, the ability to schedule, to repair, and to provide

timely delivery of ready-for-issue (RFI) engines and components to customers directly affects cost and readiness issues. SMED can reduce mean time to repair at its source, usually with minimal cost. SMED treats setup times as a controllable component within the framework of total repair process time. In contrast, the traditional approach to setups is that they are a "necessary evil" and are not controllable.

Shortening mean time to repair for an engine or component, without sacrificing safety considerations, can shorten turnaround time and increase engine availability to the Fleet. Increased engine availability will have positive and direct effects upon inventory costs and readiness. [Ref. 2] Setup reductions can also provide more efficient allocation of personnel time to repair functions instead of expending needless hours setting up a work station for the next batch arrival or waiting for the work station to be set up.

SMED can also facilitate the Naval Aviation Depot's successful implementation of MRP II. Without fully considering and conceiving improvements to the current workload management system, the true quintessence of overlaying MRP II as the new management philosophy will not be effective or attained. Reducing setup times at work stations can shorten repair lead time thereby decreasing system variability. This gives more plausibility to MRP II since it is premised on fixed lead times [Ref. 2].

B. OBJECTIVE

The objective of this thesis is to determine the feasibility and applicability of SMED in reducing repair/rebuild lead times at the Naval Aviation Depot, North Island.

C. RESEARCH QUESTIONS

The primary research questions are:

1. Is the SMED thought process feasible and applicable to the Naval Aviation Depot, North Island?
2. What are the current production/rebuild process limitations that make SMED applications desirable?
3. Can particular work stations be identified where SMED applications could reduce lead times, increase capacity, or both?

Subsidiary research questions are:

1. What is the critical path for material flow at the Naval Aviation Depot?
2. Where is the bottleneck or capacity-constrained work station, or both, located?
3. What is the priority of work for setup operations?

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

1. Scope

This thesis will limit its scope of analysis to the Power Plant Facility, Building 379, located at the Naval Aviation Depot, North Island. Within this facility, the scope

is further narrowed to concentrate on current setup procedures within the Power Plant Facility.

2. Limitations

Industrial engineers at the Naval Aviation Depot, North Island, conducted a work station capacity survey of the Fuel Control section during May 1989. No other work station capacity surveys were known to have ever been done at the Power Plant Facility. [Ref. 3] This posed problems in obtaining significant data about the actual and theoretical capacity of the various work stations. Historical production data depicting which components were processed at a particular work station was not available from the current automated management system. This prevented the analytical determination of the bottleneck and the critical path. In addition, the computerized reporting system was only capable of tracking one engine type and its components through the rebuild process by a job link number. Individual breakout of components serviced within this job link number by a particular work station would require a prohibitively long manual manipulation of records. Therefore, this author used visual observations and interviews to determine the probable bottleneck, capacity-constrained work stations, and the critical path.

3. Assumptions

This author makes no major assumption about the level of knowledge needed by the reader, except for a slight

familiarity with production management and controls. Definitions within the body of this thesis, supplemented by the glossary, should provide an understanding of pertinent concepts used within the framework of this research. The use of illustrations should also clarify concepts when applicable.

E. ORGANIZATION OF STUDY

Chapter II will provide pertinent background, within a production context, on the material flow and management within the Power Plant Facility. Chapter III will discuss SMED's development, benefits, and philosophy. Chapter IV will analyze the Power Plant Facility for SMED applicability, applying SMED's conceptual stages of development. Chapter V will present conclusions, recommendations, and areas for further research. The Appendix provides a glossary.

II. OPERATIONS WITHIN THE POWER PLANT FACILITY

An appreciation of the current mission, material flow and management within the Power Plant Facility is needed to establish the foundation for the analysis to be presented in Chapter IV. Therefore, the purpose of this chapter is to provide an overview of the system within a production context. Boyer [Ref. 2] presents a more specific analysis of the material flow, production scheduling and control for the T-64 engine.

A. MISSION

The Power Plant Facility, Building 379, is responsible for managing four separate power plant, or engine, programs and a Fleet Engine (FE) Component program. The four power plant programs include the engine types as depicted in Table I. The level of service provided to each engine is dependent upon the contract administration. The FE component program entails component repair for these power plants. This program is separate from the power plant program in that the components are not attached to engines when they arrive at the facility. The customer sends components Fleet units through supply channels for repair/rebuild. Both the power plant and FE component programs encompass engines and components received from Navy sources, interservice agreements, and foreign

military sale programs. Additionally, this shop acts as a Cognizant Field Activity (CFA), which investigates engines of crashed aircraft to determine if engine failure was the cause.

TABLE I. POWER PLANTS SERVICED

POWER PLANTS	# MODELS	AVERAGE ENGINES SERVICED/QTR	APPLICATION
T58	5	40	CH-46 Engine.
T64	6	30	CH-53 Engine.
LM2500	1	8	Fast Frigate Aegis Cruiser
F404	2	6	F-18 Engine.

B. MATERIAL FLOW AND MANAGEMENT

1. Repetitive Manufacturing Versus Job Shop Operations

Boyer [Ref. 2] considered the Power Plant Facility to be a repetitive manufacturing operation [Ref. 2:p. 17]. However, it is better classified as a job shop. Repetitive manufacturing implies the high-volume production of a discrete item that follows the same sequence of production, or repair as is this case. Assembly line operations are a good example of continuous or repetitive manufacturing. On the other hand, job shop manufacturing implies discrete batch manufacturing,

usually accomplished in small batches. Batches in a job shop environment need not follow the same sequence of operations and lead time tends to be long because of large in-process queues. [Ref. 4] The Power Plant Facility, as a job shop, organizes its departments or work centers around particular operations.

The Power Plant Facility does some manufacturing. However, a significant distinction between manufacturing and repair/rebuild operations exists. Unlike manufacturing operations, repair/rebuild operations deal with parts and components that are similar in style and from similar engine models, but each is different because of particular wear characteristics. Therefore, each part or component is processed as a separate order. This characteristic particularly justifies the job shop designation for the facility.

2. Scheduling

Boyer suggests that the T-64 engine program employs level scheduling based upon inductions scheduled by the Naval Aviation Depot Operations Center (NADOC). Nevertheless, the aggregate picture encompassing all engine programs and the FE component program does not suggest that level loading is effective as desired. First, there is no central planning agency to balance or smooth induction scheduling for both the engines and the component programs into this repair facility.

Variations in material flow on the shop floor are inevitable. Although efforts are pursuing more centralized scheduling with the approach of MRP II, the current absence of coordination between engine and FE component programs results in expediting actions and fluctuating throughput. Second, level scheduling is most effective in a repetitive manufacturing environment. Uniform plant loading is espoused by the Japanese in Just-In-Time (JIT) manufacturing. As stated previously, however, the Power Plant Facility favors a job shop structure, not a repetitive manufacturing environment. Batch sizes, expediting, and fluctuating lead times further complicate material flow, enhancing schedule variation. Thus, dynamic scheduling of diversified, low volume production is commonplace.

This author agrees with Boyer that scheduling should be based on monthly repair rates versus inductions. However, for level scheduling to be effective, the schedule must fix output for a specified period of time (i.e., quarterly or monthly). [Ref. 5:p. 567] Otherwise, changes within the system are magnified, creating variance in lead times. Interviews within the Power Plant Facility suggest expediting foils most attempts at monthly level scheduling. Top management is striving to continually improve level scheduling. However, presently it is not fixed. As Table II shows, the current engine outputs also vary on a quarterly basis.

The Power Plant Facility completed only 86% of the engines and 95% of the components scheduled during the first quarter FY90. This is an improvement and in contrast to completion per cent of schedule for the fourth quarter 1989, which were 74% and 93% respectfully.

TABLE II. ENGINE COMPLETIONS BY QUARTER

ENGINE TYPE	FY87				FY88				FY89			
	1	2	3	4	1	2	3	4	1	2	3	4
T58	41	28	38	50	47	35	54	40	30	50	33	38
T64	32	21	35	25	25	24	38	25	34	33	35	27
LM2500	8	6	9	12	6	6	5	7	4	9	8	8
F404	2	4	4	5	7	3	7	1	11	12	5	8
TOTAL	83	59	86	92	85	68	104	73	79	104	81	81

3. Bypassing Operations

The processing of every engine involves disassembly, assembly, cleaning, non-destructive testing, processing, flow test, balance, and cell test. However, bypassing operations complicate the material flow process. Under that policy, only those parts or components which require repair at a work station will enter processing at that work station. An initial

inspection department, Examination and Evaluation (E&E), implements bypassing operations following disassembly. E&E identifies the level of repair required for each part or component and routes them to the appropriate work station. Parts and components not requiring repair, or requiring specific work, bypass the normal material flow in an effort to conserve resources and money. Bypassing operations, coupled with expediting, make critical path determination extremely difficult.

4. Expediting

Each engine type has a planner and estimator (P&E) responsible for engine induction planning and its return to the customer as ready for issue (RFI). This is also true of the FE component program. P&E's schedule inductions using standard turn-around times, not work station capacity. Inefficient communication between the various P&E's, coupled with the lack of a central scheduler for all programs, complicates scheduling on the shop floor and often results in expediting for whomever screams the loudest. Expediting of repairs through the system can be recognized by counting the many "tagged items" observed throughout this facility. Expediting creates a scheduling problem whose dynamics are directly responsible for increased lead time variability and cost. Many believe MRP II will eliminate future expediting. This belief is questionable when the activities involve repair

since the times that each item is in the repair system are not known before induction.

5. System Lead Time

Because of bypassing operations, expediting, and the need to treat each part or component as a separate order, concern for the efficient management of lead time surfaces. The following elements compose lead time:

1. Make-ready or administrative time required to prepare a workpiece for processing.
2. Queue time at the work station waiting for work to commence.
3. Setup time required to prepare the work station for its next job.
4. Process (or operation) time to perform the value-added work.
5. Transportation time required to move the workpiece between work stations. [Ref. 5:p. 812]

Failure to reduce lead time can adversely affect throughput, cost, and quality. As lead time increases, throughput diminishes and inventory levels rise along with associated holding costs. Additionally, increased lead time hinders flexibility in scheduling and the early correction of quality problems. At present, long lead times plague many work centers, particularly within the Machine Shop. Long setup times and processing times are the primary contributors to long lead times in many areas. Setup times of two to six hours

and processing times of eight to 16 hours are not uncommon in the Machine Shop.

6. Process and Transfer Batches

A "process batch" is a product lot size small enough to be processed in a given time period. The lot size for a process batch may vary in size or remain fixed, depending on the shop floor organization and scheduling. The time period for a batch to be processed at a work station is composed of setup time and processing time components. One cost associated with a process batch is the setup cost. A "transfer batch" refers to the amount of the process batch moved between work stations. It should never be greater than the process batch and may also vary in size or remain fixed. Some costs associated with transfer batches include inventory carrying costs and material handling costs. [Ref. 5:p. 812]

The purpose in distinguishing a process batch from a transfer batch provides a means to reduce system lead time. As an example, consider Figure 1 [Ref. 5:p. 813]. Three operations are required to complete production of one item. The processing times required in each operation are shown at the top of the figure. On the left hand side of the figure, the process batch and the transfer batch are equal in size. This means that the batch is not transferred to the next work station until processing of the entire batch is completed. The total lead time required is therefore 2.10 minutes per unit or

2100 minutes for 1000 units. The example on the right hand side of the figure varies the process batch in operation 2 (only one setup is required) and reduces the size of the transfer batch. By using transfer batches smaller than the process batch (and by reducing the process batch size in operation 2), the wait time for the work stations downstream is reduced and total lead time is shortened to 1.31 minutes per unit or 1310 minutes for 1000 units.

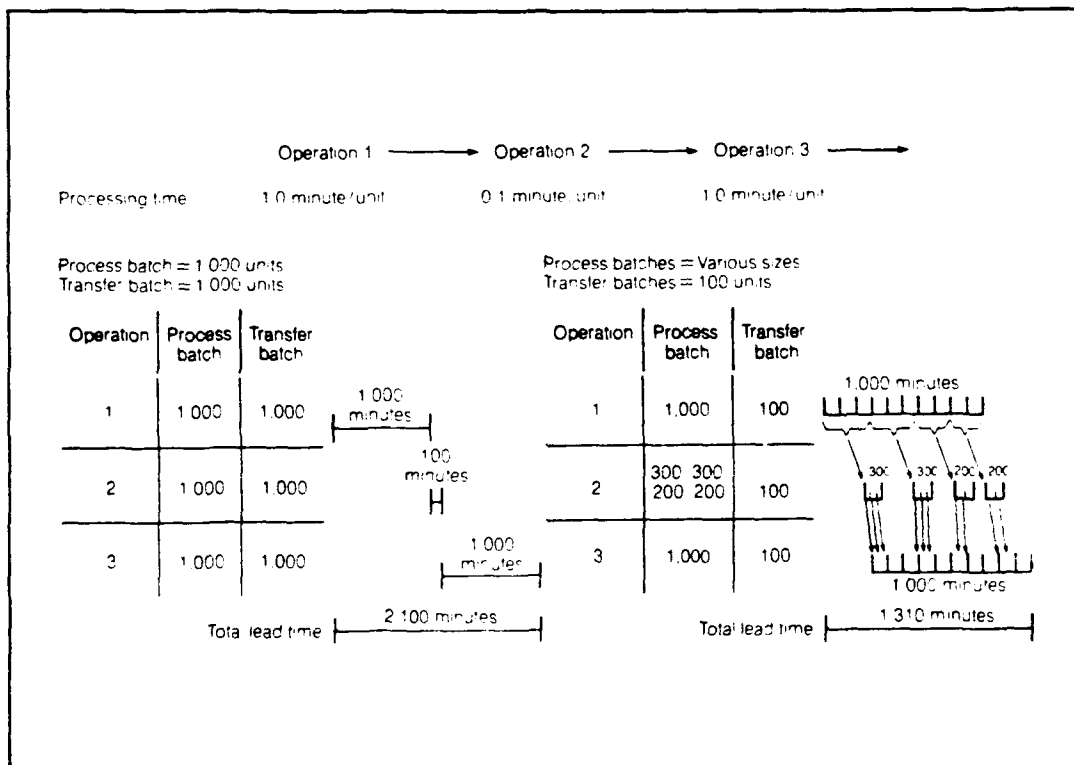


Figure 1. Effect of Changing Process and Transfer Batches Upon Lead Time

Other advantages of having transfer batches smaller than the process batch can include reduced work-in-process (WIP) inventories, quicker identification of quality problems,

quicker implementation of engineering changes (reducing scrap), and a more even flow of material between work stations on the shop floor. [Ref. 6:pp. 36-67]

Within the Power Plant Facility, the process batch is variable. Whenever possible the Power Plant Facility tries to batch like parts and components requiring repair. Nevertheless, expediting and bypassing operations conducted by E&E often force process batch size to one for most work stations. Such a low process batch size normally means more required setups and increased costs if setup time, the concern of this research, cannot be reduced.

The transfer batch size within the Power Plant facility is also normally one. As soon as a work station finishes processing a part or component the part is passed to the next work station for further processing.

This author does not advocate restricting the system by fixing process batch size (like Figure 1), but instead, promotes management of bottleneck and critical work stations to determine the production flow. This is a philosophy espoused by optimized production technology (OPT), which combines the best features of MRP II and Just-in-Time (JIT). [Ref. 7] Nevertheless, it is this author's belief that transfer batches should remain small (one in this case) since any increase would add to lead times, even if work centers were located closer together to reduce transportation time between work stations. Additionally, the small process batches

generated by the system (one in most cases) are desired since they can provide more flexibility to production (discussed in Chapter 3), but are economical only if setup times are reduced. As this thesis will show, significant lead time reductions are possible by reducing setup times using SMED.

7. Capacity Utilization

Capacity utilization studies of the Power Plant facility to determine actual work station capacity utilization have not been conducted to this author's knowledge, except for the Fuel Control area. Regardless, interviews with Power Plant personnel and personal observations suggest that present engine and component inductions do not exceed available capacity. Shortfalls in personnel availability do exist, resulting in many idle machines on a daily basis. Over a four-day period, idle machinery exceeded 50%. Other explanations for this high percentage of idle machinery are that some work stations perform duplicate work and were not needed for the scheduled workload. Also, many of the current machinery exceeds 30 years in age and are no longer capable of holding small tolerances. The bottom line is that the Power Plant Facility does not appear to have exceeded its current capacity. The causes of bottlenecks observed in the system were not due to a lack of capacity, but rather the result of personnel shortages.

C. QUALITY

The small batch size of one coupled with a prevalent Total Quality Management (TQM) mindset has forced rejects and rework within this particular facility to nearly zero. Nevertheless, the tradeoff for achieving quality has increased lead times (mainly process and setup time), primarily attributable to expediting and a lack of smooth scheduling.

Achieving total quality requires continuous improvement of the process. To achieve this goal, the Power Plant Facility must consider setup time reductions as a means to reduce lead time within the process.

D. SUMMARY

Within the Power Plant Facility, long lead time is a result of current scheduling and shop floor management problems. Nevertheless, lead time can be reduced by closely scrutinizing the time elements that compose it. The least costly and most forgotten time component of lead time is setup time. Setup time reduction at critical work stations can provide a reduction in average lead time and its variability for the system. Reduced system lead time would improve throughput, reduce WIP inventories, and can reduce operating expenses like scrap and overtime. Even if a work station is not critical, lead time reduction is a process improvement that yields cost savings, quality, and efficiency of operations.

Presently, most work stations at the Power Plant facility must conduct a new setup for each batch. Since most of the batch sizes are one, many setups are required by most work stations. Therefore, it only makes sense to reduce the setup time even if the number of setups cannot be reduced. Increasing batch size is not desired since it increases total lead time.

The Japanese have realized the importance of setup time reduction as a means to achieve JIT manufacturing and zero inventory by using Single-Minute-Exchange-of-Die (SMED). SMED provides a revolutionary approach to achieving significant setup time reductions. To achieve setup time reductions requires an understanding of SMED, teamwork, and a lot of innovativeness. This will be the topic of the next chapter.

III. SINGLE-MINUTE-EXCHANGE-OF-DIE (SMED)

The purpose of this chapter is twofold. First, traditional approaches to setup operations and the benefits of reducing setup operations are examined; second, the conceptual stages of SMED are discussed. This chapter provides the framework for later analysis of SMED's applicability to the Power Plant facility.

A. BACKGROUND

In the past, setups were an event for operators, or setup teams, to resolve on the shop floor. Today, a push from top management is occurring in Japan, Europe, and North America to reduce setup times as a means of achieving a competitive edge. A successful program for reducing setup times is the Single-Minute-Exchange-of-Die (SMED). SMED encompasses the theory and techniques needed to reduce setup operations to under 10 minutes (i.e., to single-digit minutes). Developed by Shigeo Shingo in Japan, starting in the 1950's, SMED is a concept "based on theory and years of practical experimentation" that evolved over a 19-year period. [Ref. 1:p. 26] Although not every setup operation can be reduced to single-digit minutes, this was SMED's original goal.

Like Total Quality Management (TQM), SMED involves continuous process improvement from the top downward,

emphasizing employee involvement, training, and guidance on what to look for and how to significantly reduce setup operations. Attaining setup reductions can yield substantial increases in productivity and quality, while decreasing lead times, waste, and costs. Shingo has proven that "setups which formerly took days can be done in a few minutes; lead times of a month and a half can be reduced to well under a week; work-in-process inventories can be reduced by 90%." [Ref. 1:p. xiii]

SMED is built upon a value-added basis. Only those operations that help convert an item to meet the needs of a customer add value to the product. Anything else is considered to be waste (contributes no value to the product). For example, deburring and finishing operations add value to the product. Product storage, transportation to and from work stations, and inspections do not add value and hence are waste. Setups or changeover times between jobs are also waste (non-value adding). [Ref. 8]

Sometimes, the word "die" in SMED is misleading. Early applications of SMED involved stamping machines using dies. However, SMED is applicable to any activity requiring setup operations. [Ref. 9] Although the literature relates SMED to the manufacturing arena, SMED applications are universal and can apply to non-manufacturing industry as well. Wherever setup operations occur, SMED is applicable.

B. DEFINING SETUP TIME

Setup time is often a misinterpreted, vague term. This author defines setup time as the changeover time that starts when the last good product is completed by a work station and ends when the first good unit of the next product is produced consistently, without further adjustments. This is in contrast to the Power Plant facility's definition.

Their definition of setup time is the classical one normally used in manufacturing; namely, "the time when the job is sitting behind the machine and the machine is being setup with the proper tooling." Other activities associated with preparing a work center to perform labor or add value to a product (to include but not limited to obtaining necessary technical data, holding fixtures, special tooling, etc.) are called preparation time. [Ref. 3] The differences between this author's and the Power Plant facility's definition of setup time will be made evident in the following sections.

C. TRADITIONAL APPROACHES TOWARD SETUP OPERATIONS

To gain an understanding of the importance of setup time within production activities, it is necessary to first explore traditional approaches to dealing with setups as necessary, but non-productive activities. Then, the contrast between traditional approaches and SMED's revolutionary approach to dealing with setups should become apparent.

Setup operations were traditionally accepted as events having a fixed set of activities and the time to perform them is known and constant. As consumer interests grow, so does the demand for special orders and variety of a product. The result is a need for diversified, low volume production. With special orders and small lot production, the number of setups required increases. In dealing with this problem, producers usually adopt one of the following three strategies. [Ref. 1:p. 12-19]

1. Knowledge and Skill Yield Efficient Setups

Two individual qualities, knowledge of the equipment and skill in conducting setup operations, traditionally prompted the need for specialists called "setup engineers" during setup operations of complex equipment. Traditional thinking resulted in the training of personnel to accomplish setup operations. The possibility of reducing the complexity of a setup operation was often overlooked as a more efficient use of personnel, training monies, and time. [Ref. 1:p. 14]

2. Large Lots Reduce Setup Operations Required

Traditional thought has used large lot production to lessen the effect of long, and numerous, setup operations. Combining larger lot sizes with long setup times lessened the impact of setup times on total operation time. As Table III illustrates, increasing lot sizes decreases the average man-hours required per unit produced, but at a diminishing rate. In addition, as setup operations become longer (from four to

eight hours in this case), the more effective are the results of increasing lot size. Decreasing the number of setups required by using a large lot philosophy led producers into believing they had done their best to achieve increased productivity per man-hour. [Ref. 1:p. 15-16] The possibility of reducing setup times was not considered.

TABLE III. RELATIONSHIP BETWEEN SETUP TIME AND LOT SIZE

Setup Time	Lot Size	Process Time Per Item	Operation Time Per Item (including setup)
4 hr.	100	1 min.	$1 \text{ min.} + (240/100) = 3.4 \text{ min.}$
4 hr.	1,000	1 min.	$1 \text{ min.} + (240/1,000) = 1.24 \text{ min.}$
4 hr.	10,000	1 min.	$1 \text{ min.} + (240/10,000) = 1.024 \text{ min.}$

Setup Time	Lot Size	Process Time Per Item	Operation Time Per Item (including setup)
8 hr.	100	1 min.	$1 \text{ min.} + (480/100) = 5.8 \text{ min.}$
8 hr.	1,000	1 min.	$1 \text{ min.} + (480/1,000) = 1.48 \text{ min.}$
8 hr.	10,000	1 min.	$1 \text{ min.} + (480/10,000) = 1.048 \text{ min.}$

3. Strategy of Economic Order Quantity (EOQ)

The consequences of large lot production often led to excess production substantially exceeding demand and to resultant large inventories. The long times between setups also required additional inventory as a buffer against uncertain demand. These large setup times and large lot sizes forced producers to make a tradeoff between setup times (and

the associated costs) and the costs associated with carrying inventory and incurring backorders or lost sales.

In most plants, setup times are a leading determinant of economic order quantities (EOQ). Long setup times increase the chances that large batches will be needed to accommodate EOQ calculations for the most cost-effective run quantity [Ref. 10].

D. BENEFITS OF REDUCED SETUP TIMES

SMED's ability to reduce average setup times to one-fortieth of the times originally required makes SMED a revolutionary process. [Ref. 1:p. 113]. The assumptions that setup times are fixed and that workers performing setups are required to possess a certain skill or experience level is the fallacy that pervades the traditional approach to setups. Setup time reductions through SMED relax the implicit constraints of the traditional approaches discussed above and offer numerous benefits. Setup time reductions may provide the following benefits.

1. Lower Skill Level/Knowledge Required

SMED advocates simplifying setups and procedures to alleviate the need for specialized setup people. Simplified setups foster increased safety, standardization (ease of tooling changes), elimination of setup errors, and improved quality [Ref. 1:p. 116]. Further, more efficient use of personnel and productive time are achievable. One plant cited that by "using SMED, an unskilled worker in charge of the machine was able to complete in seven minutes and thirty-eight

seconds an operation which previously had taken a skilled specialist about an hour and a half to perform." [Ref. 1:p. 117] Such achievements are not unusual through SMED implementation.

2. Elimination of the EOQ Concept

SMED applications illustrate that drastic reductions in setup times are possible, invalidating EOQ model assumptions and worth in determining economic lot sizes. Justifying large lots to reduce the effects of setup times is no longer a valid rationale. With the development of SMED, "the concept of economic lots has disappeared from the profit-engineering agenda." [Ref. 1:p. 19] Small batches are now feasible and the need to balance setup costs and inventory holding costs is no longer required. To illustrate this point, consider the following two examples.

First, assume setup times are in the single-minute range. As Table IV illustrates, increasing lot size has negligible effect on decreasing total operation time. Man-hour and setup time savings resulting from combining lots are minimized. The marginal benefits of large lot production are slight when setup times are in the single-minute range (only 3% in this case). [Ref. 1:p. 19]

Now, assume setup times are initially several hours. As Table IV suggests, reduction to the single-minute range for a lot results in a significant increase in work rate and

productive capacity [Ref. 1:p. 19]. This increase in productivity is generally achievable at relatively low cost [Ref. 1:p. 117]. The marginal benefits of reducing setup times are significant (nearly 70% in this case). This dramatic reduction in setup time makes smaller lot production possible.

The above examples illustrate that the traditional EOQ model can no longer assume fixed setup times. With SMED, this assumption must be relaxed. In practice, SMED has proven substantial setup time reductions are possible. Long setups are now being questioned, not accepted, as attitudes toward setup times change.

TABLE IV. RELATIONSHIP BETWEEN SETUP TIME AND LOT SIZE

Setup Time	Lot Size	Process Time Per Item	Total Operation Time Per Item (process time + setup time)
3 min.	100	1 min.	$1 \text{ min.} + (3/100) = 1.03 \text{ min.}$
3 min.	1000	1 min.	$1 \text{ min.} + (3/1000) = 1.003 \text{ min.}$

Setup Time	Lot Size	Process Time Per Item	Total Operation Time Per Item (process time + setup time)
4 hr.	100	1 min.	$1 \text{ min.} + (240/100) = 3.4 \text{ min.}$
3 min.	100	1 min.	$1 \text{ min.} + (3/100) = 1.03 \text{ min.}$

3. Reduced Lead Time

As discussed in the previous chapter, administrative time, queue time, setup time, process time, and transportation

time compose lead time. Setup time reduction has little or no effect upon administrative and transportation time. Yet, setup time reductions do influence production cycle time, which includes wait time (time a part waits for another part to be assembled), in-process queue time (time a part waits for an available work station), setup time, and process time [Ref. 3:p. 804]. Shingo highlights three strategies for reducing production cycle time. When used together, notable reductions in production cycle time and lead time are possible. These strategies involve reducing in-process queue time, using smaller transfer batches, and producing in small lots.

In many plants, studies show that in-process queue time (includes wait time) accounts for 75-95% of total lead time [Ref. 11]. Eliminating queue time necessitates standardizing process batches and process times in each operation. This procedure results in a continuous flow system. However, it is impractical (and undesirable) to standardize process times since work station capacities are different in reality. Optimized Production Technology (OPT) advocates balancing the flow, not capacity, by letting the bottlenecks or critical work stations pace production [Ref. 7]. OPT reduces in-process queues throughout the system except in front of bottlenecks where larger buffers are needed to prevent system disruptions and to act to pace system throughput.

Using smaller transfer batches (in relation to process batches) can also reduce production time as shown in Figure 1 (Chapter II). Smaller transfer batches mean less wait time between processes. "If single-item-flow operations [transfer batch size of one] are established for, say, 10 processes, overall lot processing time can be cut by 90%." [Ref. 1:p. 120] OPT, unlike MRP, allows for overlapping processing on sequential machines by employing smaller transfer batches. These transfer batches do not have to be of equal size. [Ref. 11] Using smaller transfer lots can achieve major lead time and inventory reductions.

The third way of reducing production cycle time (and of the most interest to this author) is to produce in small lots. Of course, this requires an increased number of setups. Generally, by reducing lot size from 1000 to 100, production time can be reduced by 90%. Nonetheless, setups are increased 10 times. [Ref. 1:p. 120] With SMED's significant setup time reductions, small lot production is possible as discussed earlier. Small lot production reduces queue time and inventory levels, resulting in substantial reductions of production time and lead time. The Japanese practice batch-bashing (purposefully reducing batch sizes to identify problem areas in the production cycle) to reduce lead times and waste, and to increase flexibility, even after the inventory holding cost have been driven down to insignificant levels. Obviously, to do that they have to reduce the setup times enough to make the

small batches feasible. Setup time reductions negate the effect of the increased number of setups, increasing work rate, productive capacity, and production flexibility.

4. Reduction In Inventories

Any significant reduction of setup times makes inventory reductions possible by reducing lead time. The Japanese have demonstrated with JIT that small lot production, achieved through aggressive setup time reductions, decreases inventory levels. By reducing inventory levels, decreased space requirements, decreased safety stock levels, and decreased costs are derived benefits.

5. Summary

Setup time reductions can make small lot production possible. Innovation and commitment on the shop floor to simplify setup procedures also eliminates the need for setup engineers. As shown above, the benefits are numerous when lead times are reduced through batch, queue, and setup time reductions. The next section will describe how to reduce setup times by applying SMED.

E. THE CONCEPTUAL STAGES OF SMED

SMED differentiates between internal setups and external setups. Internal setups, commonly called Internal Exchange of Die (IED), are those setup operations that can only be done when the machine is stopped. Such operations may include mounting or removing dies and fixtures. External setups, or

Outside Exchange of Die (OED), are setup operations that can be done while the machine is running. Operations like transporting dies and fixtures to and from the work station, and ensuring the correct tools and parts are on hand and functioning prior to changeover are all activities of external setups. Earlier, this author defined setup time as the changeover time that starts when the last good product is completed by a work station and ends when the next product's good units are produced consistently, without further adjustments. IED and OED define the boundaries of this definition as later examples will show.

SMED espouses a four-stage process in reducing setup time.

1. Preliminary Stage: Distinguish Internal from External setups.
2. First Stage: Separate Internal From External Setups.
3. Second Stage: Convert Internal to External Setups.
4. Third Stage: Streamline Both Internal and External Setups.

SMED is a continuous process of improvement which reduces internal setup functions by eliminating them or making them external setup functions and, as such, it can be viewed as part of TQM.

Typically, setups can be separated into four basic steps, each accounting for a typical percentage of total setup time. These steps are: preparation, after-process adjustments, and function checks of raw materials, tools and attachment

devices (30%); attachment and removal of dies, blades, fixtures, etc. (5%); centering, dimensioning, and setting operating conditions (15%); and trial processing and adjustments (50%). By analyzing setups using SMED's four stages (and understanding why SMED works), these percentages of total setup time become meaningless when setup times are reduced from hours to two or three minutes. [Ref. 1:pp. 21-31]

1. Preliminary Stage: Distinguishing Internal From External Setups

In many companies, preparation work for a job may not commence until completion of the previous job. Once the machine stops, the scurry to commence the next setup begins. Precious process time is wasted as the machine sets idle. Distinguishing internal from external setups is an important first step to eliminate wasted time at a work station. The success of setup reductions will ultimately hinge upon how well this preliminary stage and the first stage of SMED are accomplished.

Differentiating internal and external setups requires an in-depth familiarity with operations, personnel, and work stations on the shop floor. Industrial engineers should initiate a close examination of setup operations conducted at a work station and develop an accurate, detailed checklist enumerating all operations, tools, and parts involved. This list serves as a starting point for determining which

functions are IED or OED. It also is a reminder checklist for future setup operations and management planning to prevent oversight of IED or OED operations.

Industrial engineers may use a stopwatch, worksample, or interviewing methods. Videotaping is also a very effective alternative. Following videotaping, operators can provide a description of events and make recommendations to achieve better setups. Videotaping serves as a second set of eyes, capturing each detail of the setup process and aiding in training current and future operators and managers. [Ref. 1:pp. 29-36]

2. First Stage: Separate Internal From External Setups

After formulating a list of activities performed in a setup operation, internal and external setup activities are separated. Once separated, external activities are carried out while the machine is running. Shingo claims this step is the most important step of the SMED process. Successful completion of this step can provide a return of 30-50% reduction in setup time. [Ref. 8]

Continually questioning why a setup activity is on the checklist is important. Industrial engineers should not allow old ways of doing business to overshadow the questioning of current procedures. The objective is to shorten the IED list as much as possible in the beginning. After differentiating IED and OED activities, the industrial engineer develops a

separate list for each. These lists provide a worksheet for all future setups. To ensure continuous improvement of setup operations (IED and OED activities), operators should continually update these worksheets upon discovery of more effective ways to complete setup operations. [Ref. 12]

The use of visual controls can augment checklists, providing an at-a-glance indication of the availability of all tools or parts required for a particular setup. Shingo preaches the importance of establishing a specific checklist and table for each machine for this purpose. [Ref. 1:p. 35] The Japanese have proven that visual aids can increase productivity and provide better communications to personnel than do complicated written instructions. Visual controls may include: tool templates which contain drawings or outlines of tools required for a particular setup; boards showing status and location of dies, fixtures, and shop scheduling; and consolidated operating procedures detailed on placards, procedural charts, or in written form near machines (rather than buried in user's manuals). [Ref. 13]

Operators should also adopt a system for functional operation checks of tools and parts to complement checklists and visual controls. This is an OED function. Failure to complete successful functional checks before changeover occurs results in an OED activity taking place while the machine is down - a waste of potentially productive machine time. Additionally, transportation of tools, dies, parts and

fixtures is an OED activity that requires completion prior to changeover. [Ref. 1:p. 35] Although this seems like common sense, operators often neglect it.

Normally, operators should not shut down a machine before accomplishing all OED activities, to include positioning material and tools in front of the machine and performing functional checks. If the operator cannot leave the machine during operation, then he must make other arrangements to complete OED activities prior to machine shut down.

3. Second Stage: Convert Internal to External Setups

Although the first stage is capable of significant setup time reductions of up to 50%, this alone will not achieve SMED's goal of setup times of under 10 minutes. Further setup time reductions may be achieved by converting internal activities (IED) to external activities (OED). In order to do this, industrial engineers or operators should reexamine each elemental IED operation with an open-minded attitude and, if possible, develop a means of converting them to OED operations. This stage is analysis oriented.

Shingo advocates five whys be asked during this analysis. In addition to looking at what is being done, where it is being done, by whom, when, and how, the question why must be asked five times. Why do we do it this way? Because we always have done it this way. Why? Because when we last looked at it in 1984, we decided that of all the possibilities, this was the best one. Why? Because it used the fewest number of people and we were really short-staffed in 1984. Why? Because the new machine tool plant in the next county opened that year and they hired most of the skilled workers in the area. Do you

see how thorough analysis can help understand what is going on? Why? Why? Why? [Ref. 8]

This is the point where sound problem analysis become important. Cost of change is a consideration. However, operators can perform many minor modifications in-house at relatively low costs. In this stage, setup time could be reduced another 30%. This equates to an overall 80% reduction in total setup time. [Ref. 12]

SMED espouses three techniques that can aid the conversion of IED to OED: the completion of operations in advance of changeover; function standardization; and the use of intermediary jigs. The following examples illustrate each of these techniques. These are but a few of the countless examples where IED has been transformed to OED. [Ref. 1:pp. 41-51]

a. Completion of Operations in Advance of Changeovers

In a repair environment, components often require a certain level of preparation before machine processing can commence. This could include removing safety wire or protective coverings, sealing apertures, pre-cleaning, or metal-spray applications. Within a manufacturing environment, preheating tools or dies is sometimes required in die casting and plastic molding operations. In this case, processing cannot commence until the tool or die is preheated to the desired temperature.

Often, operators prepare a component, tools, or dies during machine idle time. Performing such operations as OED can reduce machine idle time (and setup time).

b. Function Standardization

"Function standardization calls for standardizing only those parts whose functions are necessary from the standpoint of setup operations." [Ref. 1:p. 42] Functions essential to setups include dimensioning, centering, securing, expelling, gripping, and maintaining loads [Ref. 14]. The industrial engineer or operator must decide which functions (and which parts within those functions) can be standardized on a particular machine. For instance, Figure 2 depicts two different sized dies used in press operations (measurements are in millimeters). This figure illustrates a method of standardizing closed die height (to avoid unnecessary setup times) by standardizing the die height. Function standardization of die height is achieved by using shims welded to the dies. Function standardization of clamping height is also maintained, where the same clamp or bolt can be used to attach either die to the machine. This reduces the skill required to attach dies, simplifies setups, and improves die and clamp management.

c. Intermediary Jigs

The use of intermediary jigs also provides function standardization. Intermediary jigs are standard size jig

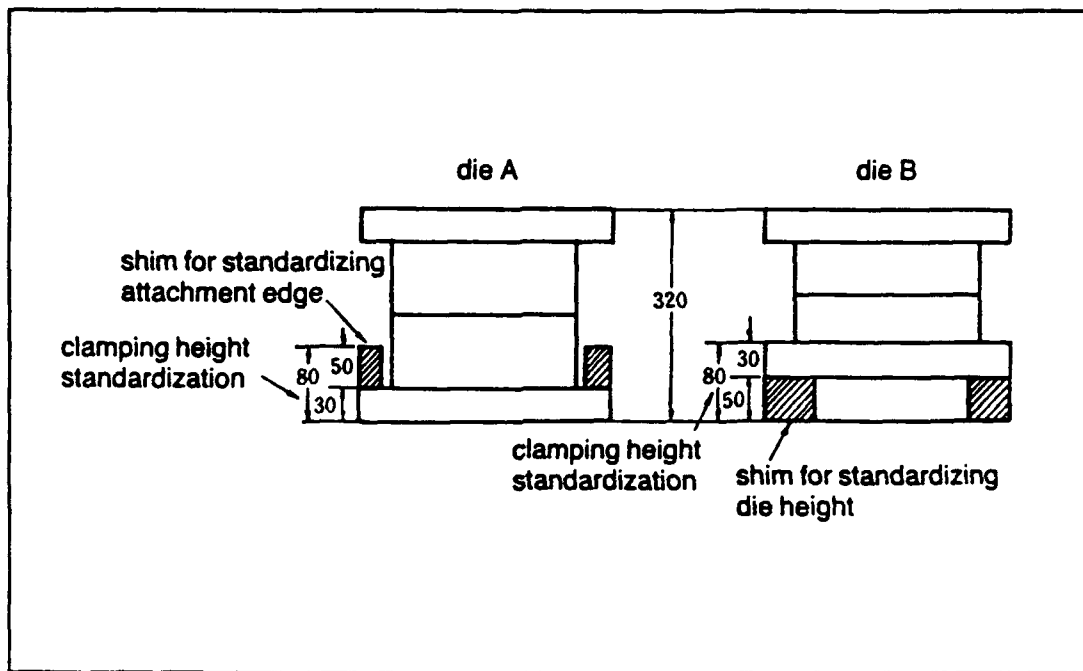


Figure 2. Function Standardization of Die Height and Clamping Edge

plates or fixtures used by operators to attach similar workpieces. For instance (in a batch processing situation), as the operator processes one workpiece, the operator or an assigned team centers and prepares the next workpiece as an OED activity on a duplicate intermediary jig or fixture. When processing of the first workpiece is complete, the second jig with its workpiece is ready for attachment to the machine. This procedure is also applicable to a single-batch situation. However, in a single-batch case, there is no duplicate intermediary jigs since each setup will be unique. Preparing a follow-on workpiece on a jig or fixture while another is being processed is one method to complete operations in advance of changeovers. Intermediary jigs avoid preparation of

the workpiece on the machine during shutdown periods, reduce time required for centering operations on a machine, and reduces machine idle time.

4. Third Stage: Streamline Both Internal and External Setups

"Although the single minute range can occasionally be reached by converting internal to external setup, this is not true in the majority of cases." [Ref. 1:p. 30] The goal of this stage is to streamline elemental operations (IED and OED) to reduce setup times under 10 minutes. Industrial engineers or operators must perform additional analysis for each elemental operation to determine how to increase its efficiency. This stage may be completed simultaneously with stage two above or as a separate stage. Shingo recommends the latter. Achievement of a 90% overall setup time reduction is possible upon successful implementation of streamlining techniques [Ref. 12] Industrial engineers or operators may use the following methods to streamline OED and IED operations.

a. Streamlining Externals (OED)

Improving identification, storage, and transportation of tools, dies, and parts are OED streamlining actions [Ref. 1:p. 51]. Having well-organized tool cabinets close to equipment, organized storage racks for dies, and conducting functional checks of tools and parts prior to

turning off machines are all examples of this process. Other tools for streamlining OED operations include visual controls in the form of tool or storage rack templates, color coding of tools and dies to aid in easy location and better organization, and transporting the material and tools to the machine prior to shutdown. Operators must eliminate the search for tools and the repair of parts during machine idle time. Nevertheless, organizations cannot achieve significant setup time reductions through OED streamlining alone. Organizations must strive to achieve IED streamlining, the next topic of discussion.

b. Streamlining Internals (IED)

Several tested methods for streamlining IED are available. They include the use of parallel functions, functional clamps, and the need to eliminate adjustments.

(1) Parallel Functions

Parallel functions entail having more than one worker involved in completing setup operations. Oftentimes, one person may waste time in movement from one side of the machine to another during changeover operations. Teamwork during such operations could reduce setup time. For instance, operators can divide work on a large machine into work required to the front and to the rear of the machine. This division of work is then shared by two persons (one in the front; one in the rear). Although safety is a major

consideration, pre-agreed upon signals (i.e., buzzers and lights denoting start and stop operations) and practice can overcome such fears. Visual aid charts can also provide a listing of detailed steps and signals to avoid confusion and safety problems. Parallel operations are appealing since they may not require hiring additional personnel to perform the parallel functions. Neighboring personnel or a floor supervisor can be cross-trained to assist in parallel operations. Parallel functions are a very effective means of achieving setups under 10 minutes, reducing IED time by half in some cases. [Ref. 1:pp. 53-55]

(2) *Functional Clamps*

Direct attachment of a workpiece or a fixture to a machine is often accomplished by passing a bolt through a hole in the workpiece (or fixture) and fastening them to the machine using numerous turns of the bolt.

If the nut has fifteen threads on it, it cannot be tightened unless the bolt is turned fifteen times. In reality, though, it is the last turn that tightens the bolt and the first one that loosens it. The remaining fourteen turns are wasted. In traditional setups, even more turns are wasted because the length of the bolt exceeds that of the part to be attached. [Ref. 1:p. 55]

Functional clamping involves securing objects (fixtures or workpieces) to a machine with the least amount of effort. If the function required is clamping or holding, numerous turns are not required [Ref. 14]. Operators can reduce time and effort during attachments by minimizing

motions to a single-turn, single-motion, or screwless (interlocking) method. This is accomplished by reducing the number of threads required to be engaged in tightening operations. Figure 3 provides some examples of single-turn, single-motion, and interlocking methods. [Ref. 1:pp. 55-66]

In Figure 3, three types of functional clamping using the single-turn method are shown. With the U-shaped washer method, single-turn clamping and loosening can be achieved. Here, the inside diameter of the core is larger than the nut, but smaller than the U-shaped washer. By loosening the nut one-turn, the washer can be easily removed from (slid off) the bolt and the core being held in place can then be removed easily, without removing the nut. Another core can then be easily attached by sliding it over the nut, replacing the U-shaped washer, and tightening the nut one-turn. [Ref. 1:p. 58]

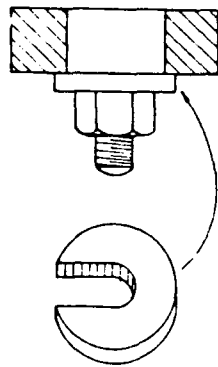
The U-slot method, similar in principle to the U-shaped washer method, can also provide strong, single-turn clamping. Here, a dovetail groove or channel is cut in the attachment surface, allowing the head of a bolt to be inserted into the channel. By cutting a U-shaped slot in the die or fixture, the fixture can then be slid into position with the bolt in the U-shaped slot of the die, and then clamped into place with one-turn of the nut. Another alternative to direct attachment using single-turn tightening is the clamp method. Again, the nut only requires one-turn

tightening on a clamp that presses down on a die or fixture.
[Ref. 1:p. 59]

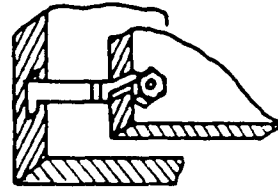
An example of one-motion fastening is also provided in Figure 3. "The concept of securing an object with a single motion lies behind a number of devices, including: cams and clamps; wedges, tapered pins, and knock pins; and springs." [Ref. 1:p. 60] In Figure 3, spring stops are used in a pincer-type mechanism. Here, a gearshaft had a semicircular groove cut around its circumference. Spring-loaded check pins were installed along the inside circumference of the clamping device. Thus, the correct position of the shaft is attained when the shaft is slid far enough into the clamping device to where the check pins engage the semicircular groove of the shaft. Magnetism and vacuum suction are other forms of one-motion clamping. [Ref. 1:pp. 60-61]

A screwless or interlocking method of clamping is also shown in Figure 3. The holder, or cradle, is standardized and is attached to a machine. Dies are designed to attach to the holder in a cassette-like fashion. The holder remains affixed to the machine and is not removed when the die or fixture requires changing. This method of screwless attachment can significantly simplify centering operations during setup. [Ref. 1:p. 62-63]

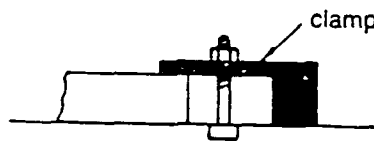
The U-Shaped Washer Method



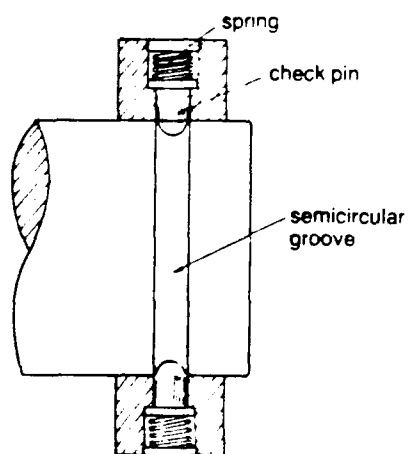
The U-Slot Method



The Clamp Method



Spring Stops (one-motion)



Interlocking Method

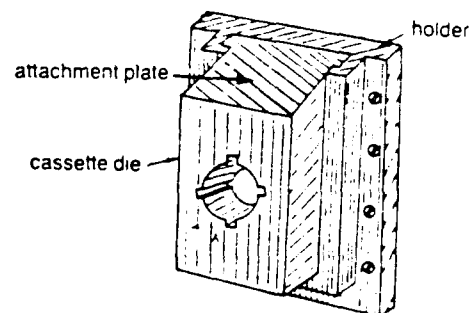


Figure 3. Examples of Functional Clamping

(3) *Elimination of Adjustments*

The elimination of IED adjustments is crucial to ensure setup time reductions. Shingo distinguishes between settings and adjustments. Settings involve the initial application of the workpiece to the machine. Adjustments involve the subsequent calibration required to achieve the desired setting. As discussed earlier, adjustments can account for 50% of total setup time. Through continuous process improvement, the goal is to conduct only initial operating settings. Shingo illustrates several methods to attain this goal: the use of calibrated scales; making imaginary center lines or reference points visible; and the use of the Least Common Multiple method.

(a) *Calibrated Scales*. By attaching calibrated scales on machines or by using a combination of a limited series of gauges, operators can eliminate adjustments previously made by intuition. These actions simplify setups and reduce trial runs. Accuracies on the order of .05mm are possible with calibrated scales. Finer settings on the order of .01mm and smaller are possible with calipers or dial gauges. For instance, operators can closely approximate settings during succeeding setups by simply marking setting positions on the machine. This procedure may not totally eliminate adjustments, however, it can significantly reduce them. [Ref. 1:p. 67]

(b) *Making Imaginary Center Lines Visible.*

When setups are often performed, the center of the workpiece is found by trial and error operations. This lengthy process can be greatly reduced by making imaginary centers visible. Making imaginary center lines visible can eliminate adjustments and scrap during centering operations. Figure 4 illustrates one method of making centerlines visible on a milling machine. In the past, milling operations required that the center of the milling machine cutter be aligned with the center of the workpiece. This was often a very tedious process requiring some expertise. The centering process was simplified as shown in Figure 4. A pair of V-blocks were installed on both the machine and the table parallel to and equidistant from the table's centerline. By using standard-sized cylindrical blocks and pressing them against the table so that they were held between the V-blocks, centering the machine cutter and the center of the table could be accomplished quicker, with less skill level required. Once the workpiece was centered on the table (i.e., using intermediary jigs or center markings on the table), the need for trial cutting was eliminated. Making imaginary centerlines or reference planes visible can reduce adjustments to settings and simplify skill levels required to perform the settings, resulting in reduced setup time. [Ref. 1:pp. 66-76]

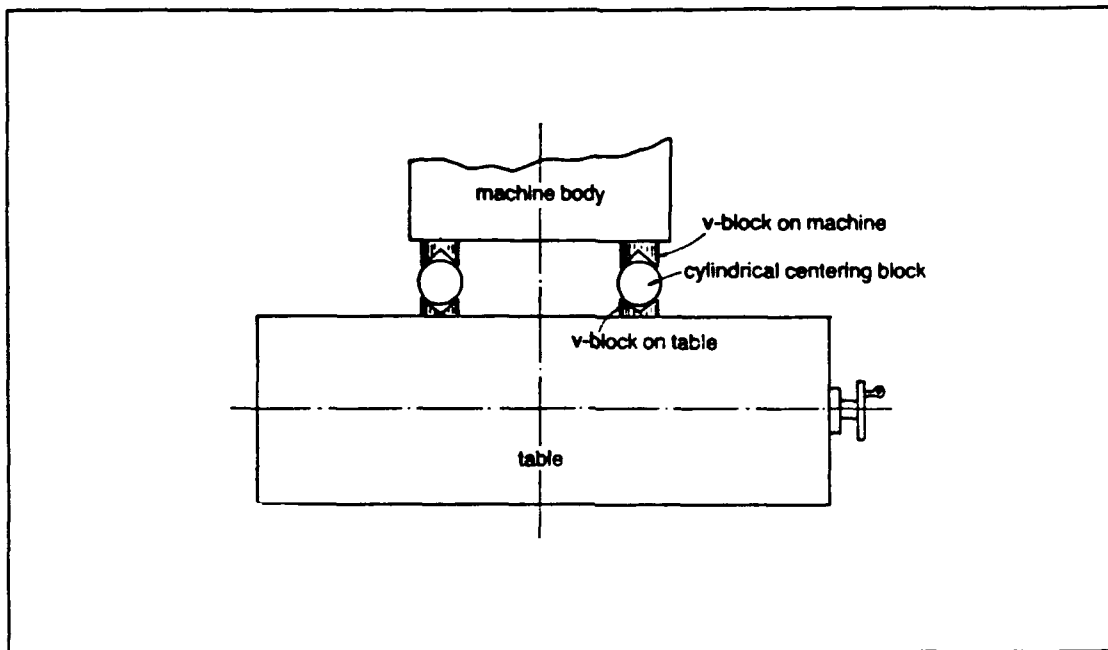


Figure 4. Making Imaginary Centers Visible on a Milling Machine (Top View)

(c) *Least Common Multiple System.* The last technique proposed by Shingo to eliminate adjustments involves the "Least Common Multiple System." This technique proposes making settings, not adjustments, by "leaving the mechanism alone, and modifying only the function." [Ref. 1:p. 76] Functions essential to setups include dimensioning, centering, securing, expelling, gripping, and maintaining loads.

The name [least common multiple system] refers to the notion of providing a number of mechanisms corresponding to the least common multiple of various operating conditions. The workers then perform only the functions required for a given operation. [Ref. 1:p. 76]

One such example is shown in Figure 5. Previously, a grinding operation performed on a small and a large shaft varied, dependent upon the size of the shaft. For small shafts, the

two points on the shaft that required grinding were closer together than the two points requiring grinding on large shafts. This grinding process required a separate setup for each different sized shaft during changeover, requiring lengthy machine shut down to adjust the distance between grinding wheels. For instance, each setup required the operator to stop the machine and to remove one grinding wheel (grinding wheel A) in order to change the size of the spacer required between the grinding wheels (larger size shafts required a larger spacer than smaller shafts). The design shown in Figure 5 eliminated the need to remove grinding wheel A and to replace spacers during changeovers. Here, two ring-shaped spacers were used (spacer A and spacer B). Notches of equal depth were cut from each ring-spaced washer at four locations along their circumference, forming four uniform peaks and notches on each washer. For small shafts, the two ring-spaced washers were rotated so that the peaks of spacer A were aligned with the notches of spacer B (top picture in Figure 5). When a larger shaft required grinding, changeover was simplified by eliminating the need to remove grinding wheel A. Now, changeover operations could be completed simply by loosening the nut holding the grinding wheels and spacers together until spacer A and spacer B could be rotated. For larger shafts, spacer A and spacer B are rotated until their peaks and notches were aligned (bottom picture in Figure 5). The mechanism (the grinder and grinding wheels) was not

changed. However, the grinder's function (grinding small and large shafts) was modified into one jig. This eliminated the need for adjustments, simplified setup procedures, and significantly reduced changeover time. [Ref. 1:pp. 66-87]

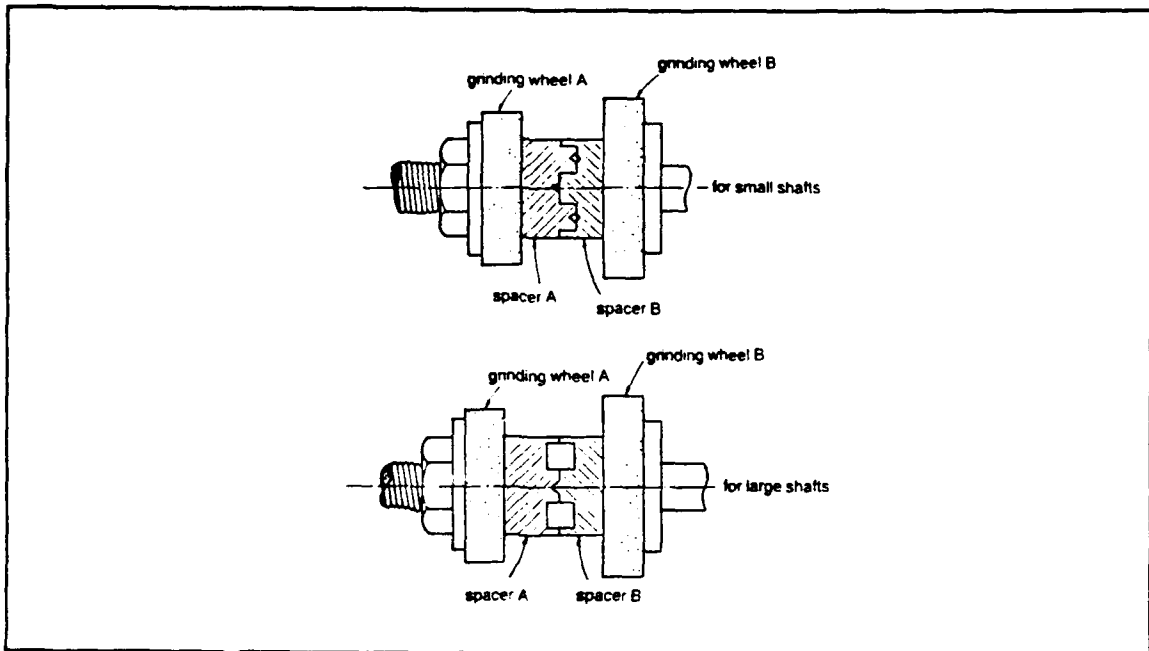


Figure 5. Least Common Multiple Technique

F. SUMMARY

SMED is a revolutionary way to approach production today and is applicable wherever setup operations occur.

SMED experience is that any time required for a change of die by traditional methods should be divided by 60 (your hours required to change should become minutes required to change). Any die change should be accomplished in ten minutes or less and can be [Ref. 14].

Although setup time reductions are possible through mechanization, organizations should avoid this approach until attempts have been made to implement SMED and streamline

current setup operations. It is much more effective to mechanize setups that have already been streamlined. [Ref. 1:p. 87]

SMED's acceptance within organizations requires cultural change. For SMED to be effective, team work, creativity, and the desire to pursue continuous improvement must be common goals of each individual within the organization. The management system must also be open to change before taking advantage of the additional productivity potential offered by effective SMED applications [Ref. 10].

Organizations can reduce setup times up to 90% by conducting a thorough operations analysis utilizing the SMED stages discussed in this chapter and by getting everyone involved. The benefits associated with such an achievement are indeed countless as discussed within this chapter.

Figure 6 provides a summary of SMED's conceptual and practical techniques [Ref. 14:p. 35]. This diagram synthesizes the four SMED conceptual stages. The centerline distinguishes between external setup (above the line) and internal setup (below the line). During the preliminary stage, the large white box suggests that no distinction exists between external and internal setup. Progressing from the preliminary stage to stage 1, external operations and internal operations are identified and separated using the methods shown. Progressing from stage 1 to stage 2, internal setup operations are converted to external setup operations by preparing operating

conditions in advance, employing function standardization, and using intermediary jigs. Moving to stage 3 requires streamlining (reducing) both external and internal setup operations using the practical techniques shown. Understanding SMED's conceptual stages provides better insight to understanding SMED's applicability to the Power Plant facility at the Naval Aviation Depot.

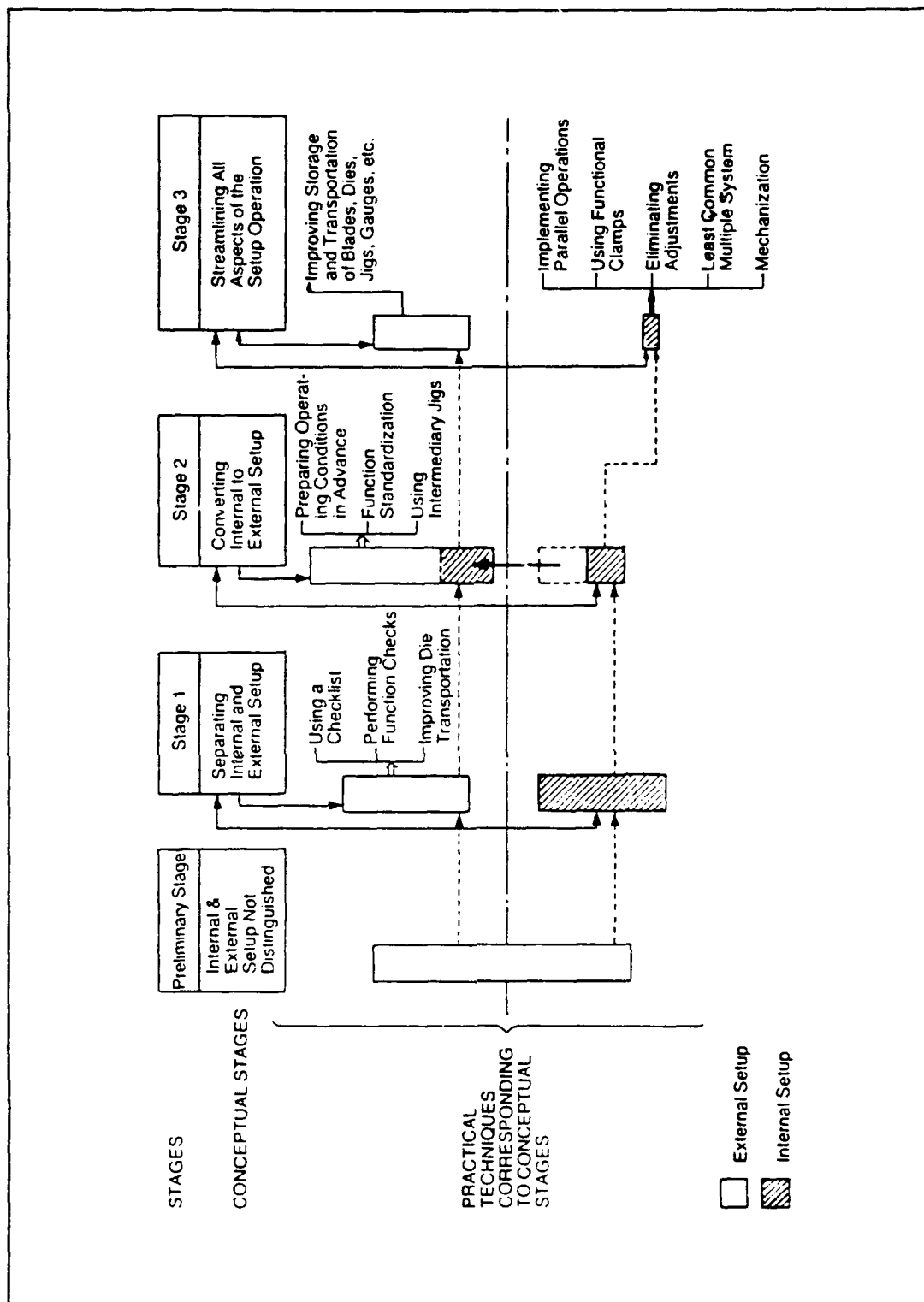


Figure 6. SMED's Conceptual Stages and Practical Techniques

IV. SMED APPLICATIONS TO THE POWER PLANT FACILITY

This chapter provides an analysis of SMED's applicability to the Power Plant facility. First, the author will present constraints imposed by the Power Plant facility and their effect upon the scope of this analysis. Next, a synopsis of two work centers studied during this research will be provided. Finally, these work centers will be analyzed using the conceptual stages of SMED.

A. BACKGROUND

Several constraints encountered while working with the Power Plant Facility limited the methodology and scope of this research. These limitations were discussed in Chapters I and II. In general, the absence of work station capacity data coupled with the difficulty in obtaining sufficient component flow data through specific work stations to be able to generate the associated statistical distributions prevented the analytical determination of bottleneck work stations and the critical path associated with the repair of a component. This lack of data also inhibited the development of an explicit priority of work to establish which setup reductions would benefit throughput most.

As determined through visual observations and interviews, the critical path appeared to change daily as a result of

bypassing operations and expediting. Bottlenecks and capacity-constrained work stations also shifted daily because of system variations enhanced by bypassing operations and expediting. Although the author observed several critical work stations (i.e., a work station located on the observed critical path), he could not locate a bottleneck or capacity-constrained work station. The system bottleneck within the Power Plant Facility was most notably a consequence of the limited human resources. Their influence was reflected in long machine idle times between changeovers and numerous vacant machines. Some personnel were responsible for duties in more than one work centers or in more than one building.

Two work centers within this facility were subjectively determined to be on a critical path. These were the Machine Shop and the Fuel Control work centers. Both work centers processed components for all engine programs and the FE component program. Excessive work-in-process (WIP) inventories and long production times were characteristic of these centers. The remainder of this analysis will focus on these two work centers. First, a brief look into each work center is provided to orient the reader. Second, typical operating procedures within these work centers will be examined within the context of SMED's conceptual stages to illustrate SMED's applicability to the Power Plant Facility and the significant benefits available through setup time reductions.

B. WORK CENTER HIGHLIGHTS

1. Fuel Control Work Center

The Fuel Control work center tests and adjusts fuel control units, oil pumps, pressure valves, and actuators for each power plant program and the FE component program. If these components require further repair before receiving RFI certification, this work center will route the unit to the appropriate work center for processing. Once repaired, that unit is returned to the Fuel Control work center, where they retest the unit before receiving RFI certification. A retest rate for fuel control units of 30-75% is not uncommon. When testing components, this work center uses different test benches, each of which simulates a specific power plant type. These test benches are not interchangeable between engine types but can test all engine models for a specific engine type. Table V provides the quantity of test benches available by power plant type and the average setup and processing times required for testing the associated fuel control units. Figure 7 provides an example of the test bench used for the LM2500 engine. Currently, the Fuel Control work center operates on only one shift (eight hours long) each day over a five-day work week. The Fuel Control work center characteristically possesses a large WIP inventory backlog.

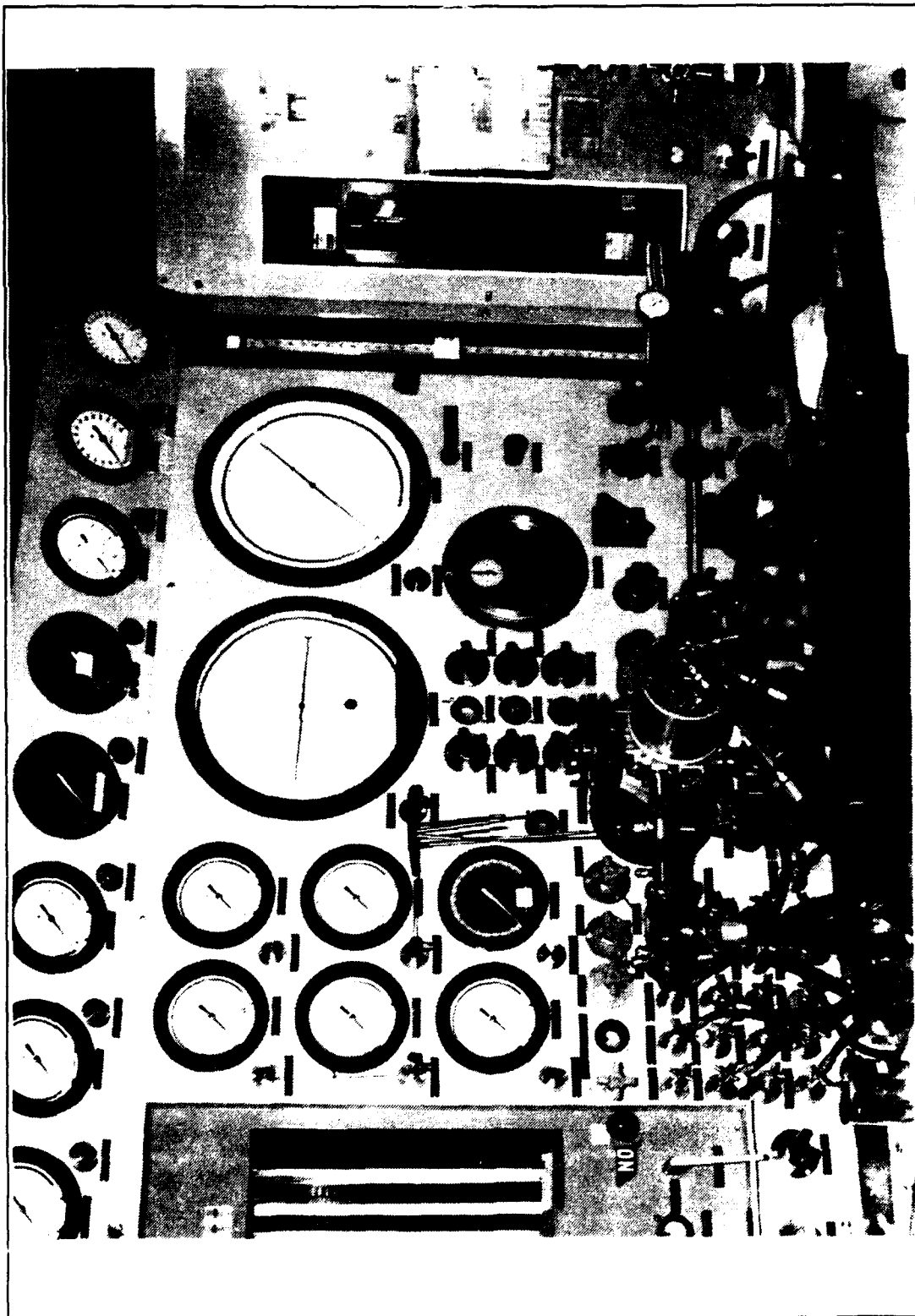


Figure 7. LM2500 Fuel Control Test Bench

TABLE V. FUEL CONTROL WORK CENTER

POWER PLANT	QUANTITY	AVERAGE SETUP TIME	AVERAGE PROCESS TIME
T-64	4	60 min	13 hr
T-58	3	40 min	15 hr
F-404	3	45 min	7 hr
LM2500	2	40 min	6 hr

2. Machine Shop Work Center

The Machine Shop performs machining operations necessary to repair, modify, or overhaul power plant components and assemblies. Particular operations entail grinding, turning, lapping, and measuring component and assembly tolerances.

Like the Fuel Control work center, the Machine Shop is an operation included in all four of the engine programs and the FE component program. Large WIP inventories are commonplace. This author concentrated on several specific machines involving grinding and turning operations within this work center.

Table VI provides a listing of those machines studied and their setup and process time range. Here, a range (not an average) of times is considered since artisans use these machines to process a variety of components or assemblies, unlike the Fuel Control work center which has dedicated benches for each engine type. For instance, turning operations may involve over 100 different parts (not necessarily from the

same engine) over a variable timeframe. Depending on the work scheduled, the Machine Shop does attempt batching where possible and may dedicate a specific machine to process special components for a particular engine type. For example, the Dodge and Shipley Lathe is generally dedicated to turning (or producing) LM2500 engine components because of its ability to turn large-sized components. Figures 8, 9, 10, and 11 are photographs of the machines listed in Table VI. (In Figure 8, the workpiece is attached to a rotating work table located at bottom/center. The index head and grinding attachment is located directly behind the hoist chain, to the left of the table. In Figure 9, the workpiece is attached to a rotating work table similar to Figure 8. The table is obscured by the protective metal shrouding and is located directly in front of the worker in the white coat at bottom/center {approximately waist high to the worker and parallel to the shop floor}. The grinding attachment is located at the base of the vertical shaft that is perpendicular to the rotating table at center picture {adjacent to the light and directly in front of the worker}. Figures 10 and 11 are typical lathes and should be self-explanatory.) Currently, the Machine Shop performs for only one shift (eight hours long) each day over a five-day work week.

TABLE VI. MACHINE SHOP

MACHINE	SETUP TIME RANGE	PROCESS TIME RANGE
Vertical Turret Lathe (Bullard)	1-6 hr	2-10 hr
Vertical Grinder (Campbell)	1-4 hr	4-16 hr
Lathe (LaBlonde)	1-4 hr	2-8 hr
Lathe (25"-35" Dodge & Shipley)	1-4 hr	4-8 hr

C. SMED APPLICATION TO WORK CENTERS

The subsections below provide a snapshot view of current problems within the Fuel Control and Machine Shop work centers. These problems will be considered within the context of SMED and potential solutions or considerations will be provided where applicable. By analyzing a sampling of descriptive problems in this manner, the reader can acquire a better appreciation and understanding for SMED's applicability in a repair/rebuild environment.

1. Distinguishing Internal From External Setup

Industrial engineers monitor work center activities and develop standards from time studies for most job functions. These include some job preparation times. These time standards are recorded on a Master Data Record (MDR). Figure 12 provides an example of a typical MDR. However, the standards are not necessarily machine specific.

These time standards allow job estimators to more accurately predict how long a particular job might take,

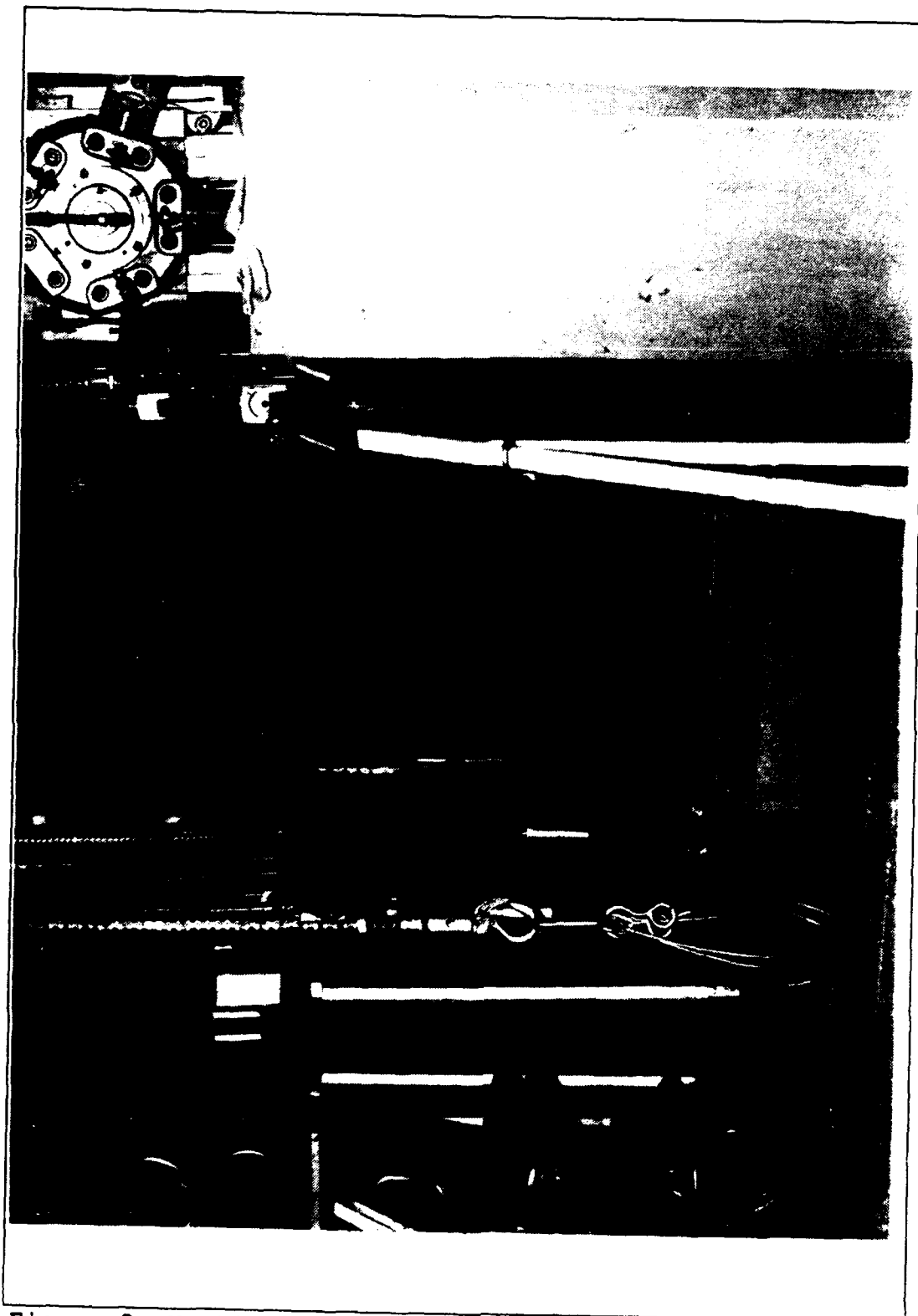


Figure 8. Vertical Turret Lathe (Bullard)

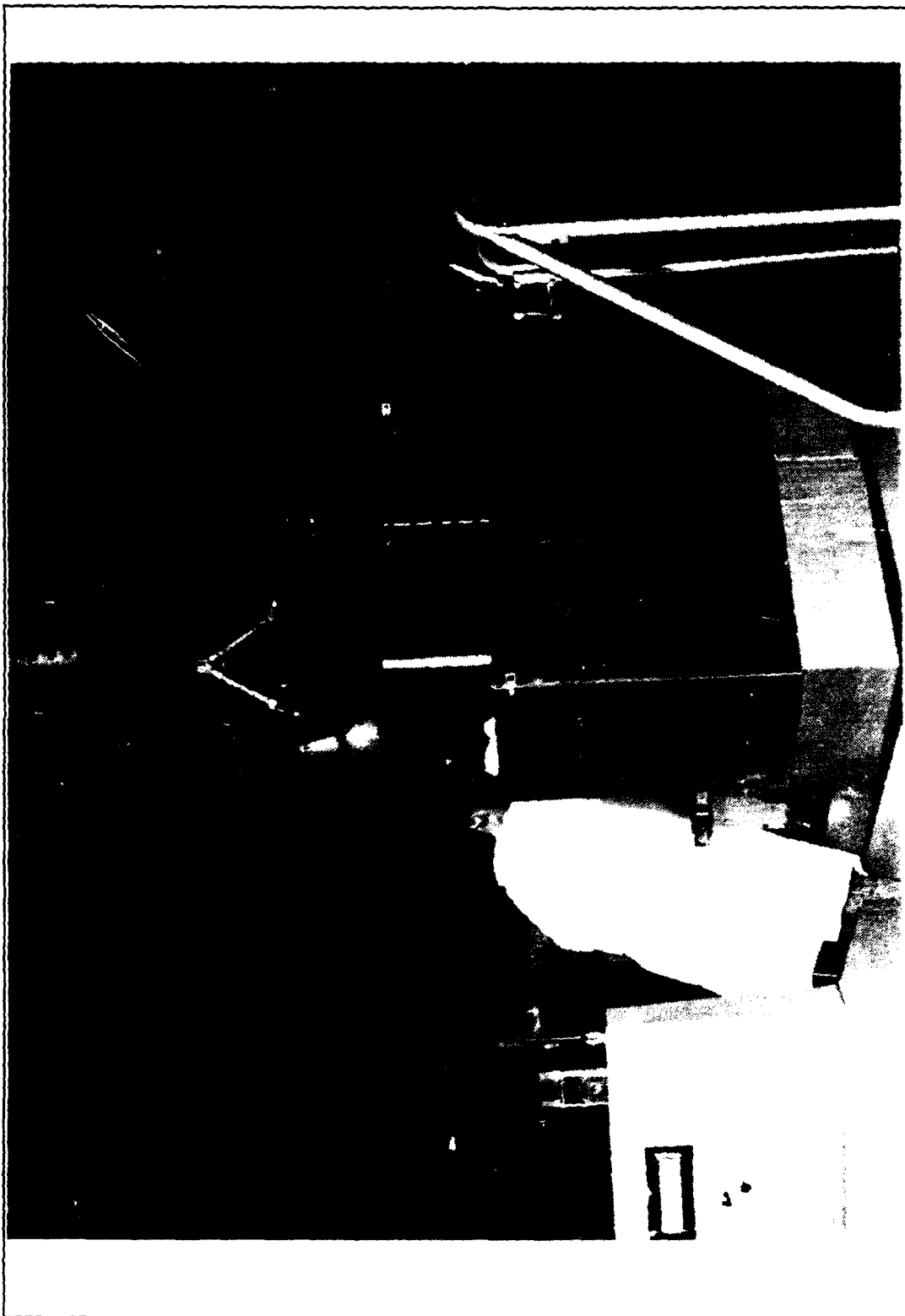


Figure 9. Vertical Grinder

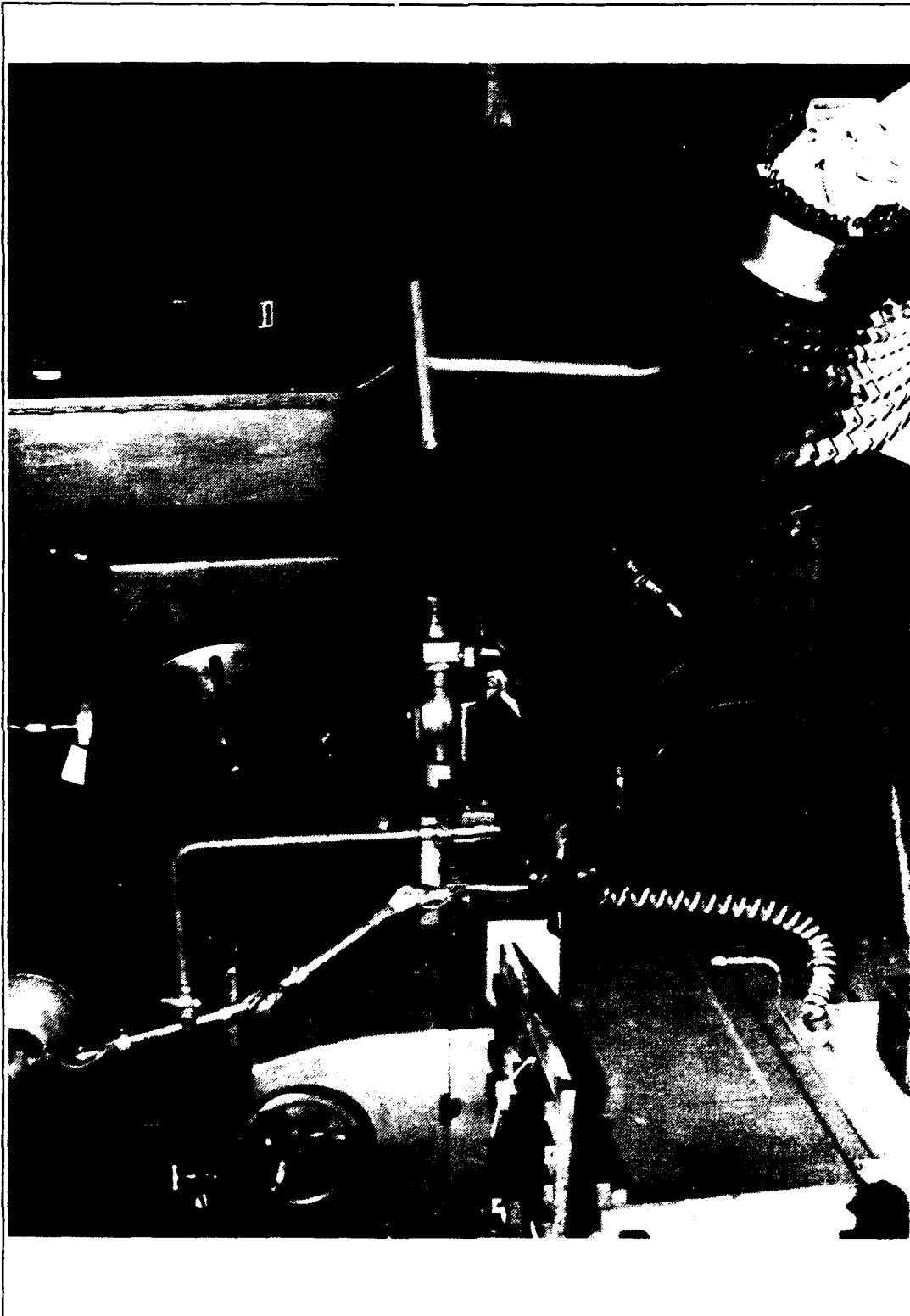


Figure 10. Lathe (LaBlonde)

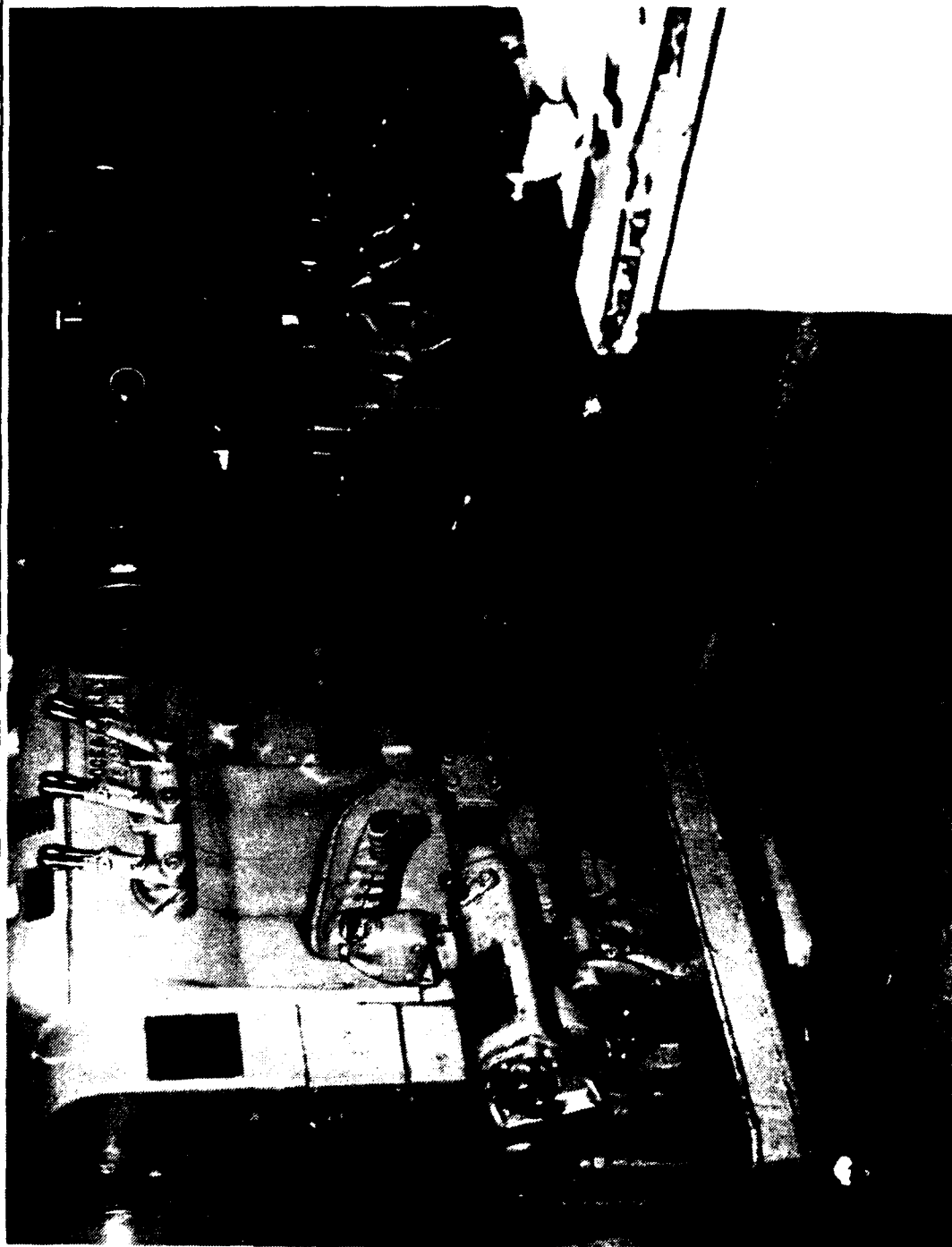


Figure 11. Lathe (25"-35" Dodge and Shipley)

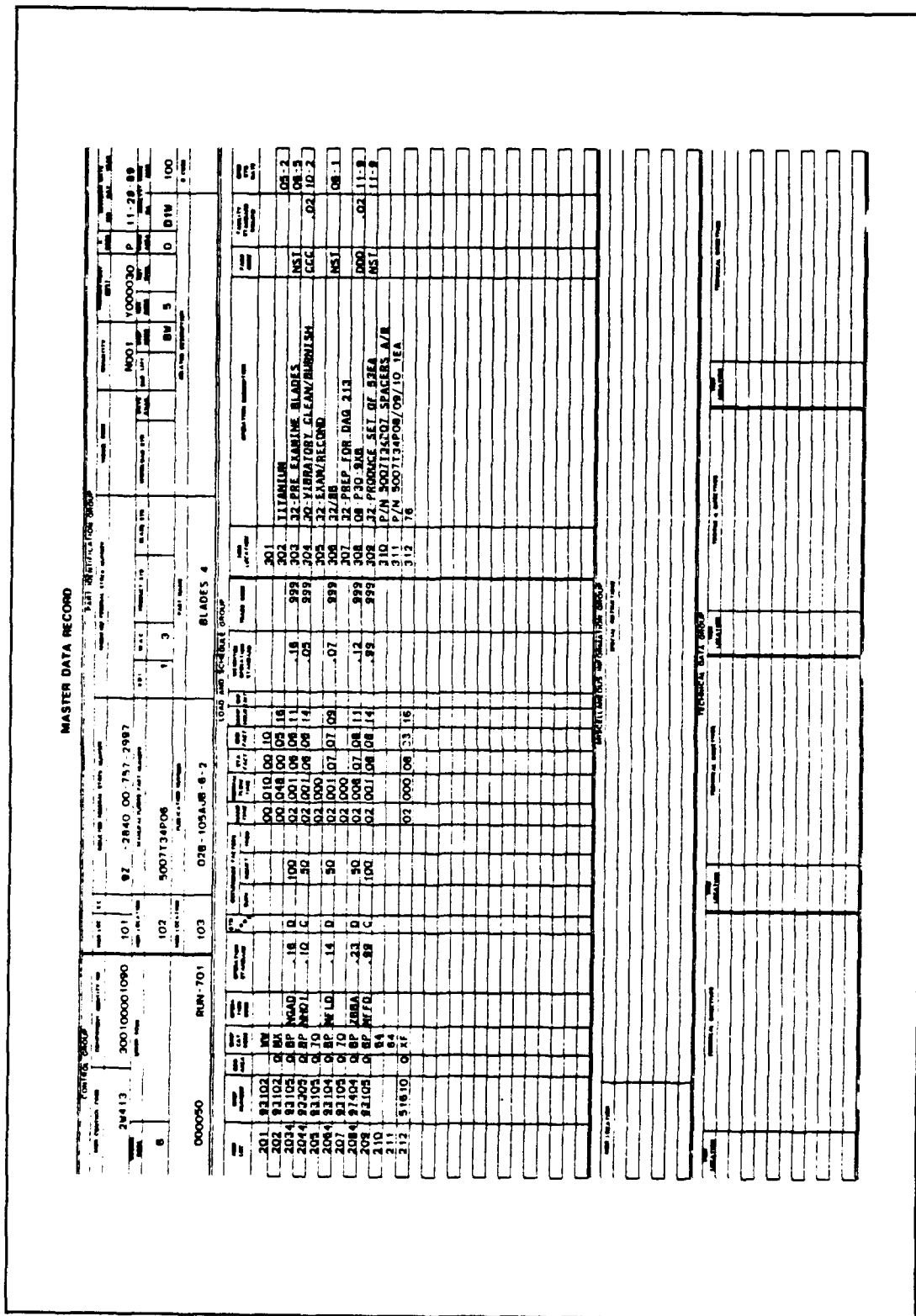


Figure 12. A Typical Master Data Record (MDR)

aiding contract negotiations, scheduling operations, and turnaround time determination for the Fleet. Breakout by job function also aids job flow determination through work centers in the Power Plant Facility. Job functions may include standard disassembly, assembly, and work activities (examine, clean, install, grind, etc.).

Presently, industrial engineers are attempting to assign setup times to job functions (not specific machines) and record them on MDR's as part of the implementation of MRP II. However, they are not representative of the true setup times for a given machine as defined within the context of this thesis. They represent only a portion of the setup times required for a particular machine in most cases.

Failure of industrial engineers, foremen, and artisans to breakout or list activities and times associated with job setup for a specific machine has created an environment of production uncertainty. Artisans perform setups based on intuition developed through years of experience, augmented by technical manual specifications. Therefore, no consistency in setups exists. Job frequency (how often a component is processed) also hinders current setups. This effect is more prevalent within the Machine Shop, since components processed are more numerous and variable than the Fuel Control work center. Within the Machine Shop, job frequency for a particular component can vary from once a day to once a year, depending on the component processed. In one case, by not

detailing past setup procedures, a lathe operator spent four hours recreating a one-hour setup for a component whose job frequency was only once a year. The machine remained idle during the entire process, wasting productive time. Even for more frequent activities, artisans rely upon previous experiences to conduct setup operations. Since standardization of setup procedures is nonexistent (varying with each artisan), setup times quoted on MDR's quickly become suspect.

Non-standardization of setup activities affects other facets during setup operations. Once changeover commences, artisans then begin locating fixtures, tools, technical information, and parts for the next job. This is most prevalent in the Machine Shop where machines are not dedicated to processing one type of component. Here, artisans locate individual tool cabinets as near as possible to machines, but determine tool requirements as the job develops, sometimes finding specialty tools adrift or borrowed by other artisans in the work center. Fixture location is sometimes difficult because of poor storage organization or failure of artisans to return the fixture to its proper location following a job. Both instances create a "search and work" environment, leading to increased machine idle time.

Within the Fuel Control work center, these effects are not as prevalent since specific components are tested on dedicated test benches and the number of setup activities

required are minimized (which minimizes tool and fixture requirements).

A detailed list of operations, personnel, tools, and material required during setup on critical machines is the first step needed to properly initiate the SMED methodology. This detailed list would establish a standard worksheet for future setups, listing fixtures, tools, and procedures required. However, development of this detailed worksheet requires time, teamwork, and dedication. Industrial engineers internal to the Power Plant facility (or external consultants) and operators detail the procedures, personnel, tools, and material required for each setup on each machine. The industrial engineers must time the procedures. This process may seem laborious, particularly within the Machine Shop where a certain machine may require the analysis of hundreds of different setup operations. Nevertheless, the worksheet provides an initial consensus of the actual details of the setup operations on the shop floor and serves as a reference checklist for future setup operations. Significant reductions in setup times reductions are not possible without first understanding current shop floor procedures and inefficiencies.

2. Separating Internal From External Setups

The Power Plant Facility's current definitions of setup time and preparation time hinder adequate distinction

between internal operations (IED) and external operations (OED). For example, preparation time standards for a setup are included as either a part of setup time or processing time, or split between the two (depending on the operation performed). Additionally, the Power Plant facility's definition of setup time fails to include the time often required for subsequent adjustments to the workpiece once attached to the machine. This is often included as processing time. SMED's definitions of IED and OED operations provide a more simple and consistent evaluation of setup operations that is easily understood down to the operator level. Clarity at the operator level is extremely important if continuous improvement of developed checklists for changeover operations is expected.

During processing operations within both work centers, machines required continuous monitoring and adjustment by artisans to achieve test readings or to achieve accurate specifications of work. Very few numerically-controlled (programmable) machines existed to allow program and walk-away processing operations. During changeover operations, artisans left machines idle for extended periods to perform finishing operations (i.e., draining fuel control units after testing, deburring operations, etc.) and to prepare the next workpiece for processing (i.e., taping casing apertures closed, placing splines between compressor blades to prevent bending during grinding operations, etc.). SMED's delineation of IED and OED setup operations provides a realistic approach to reducing

current non-productive machine idle time. But, without numerically-controlled machines, completing OED operations is not possible relative to setups if there are no extra personnel to help out (i.e., idle workers or new employees).

To accurately define setup time, industrial engineers or operators must examine each machine, and each component or assembly processed on that machine, and list the activities, personnel, tools, and material required. A clear distinction between those activities that can only be done when the machine is stopped (IED) and those activities that can be done while the machine is running (OED) is a necessity to understand the aggregate process and to begin minimizing machine idle time. Once the checklist developed earlier is categorized into IED and OED operations, the necessity of IED operations are more easily questioned and reduced to OED operations or eliminated by industrial engineers and operators.

3. Improving Elemental Operations

Converting IED operations to OED operations and streamlining the elemental operations could occur simultaneously, but Shingo suggests separating them. To ensure effective improvement of elemental operations, industrial engineers and operators must reanalyze setup operation lists or worksheets previously discussed, questioning the purpose of all activities.

The Fuel Control and Machine Shop work centers can achieve immense setup time reductions by improving elemental operations. A snapshot view of present operations indicates that significant improvements are attainable by converting IED operations to OED operations and by streamlining both IED operations and OED operations. The following subparagraphs provide examples illustrating how elemental operation improvements can benefit both work centers.

a. Converting IED to OED

*(1) Completing Operations in Advance of
Changeovers*

This method is most applicable to the Machine Shop, particularly within the arena that industrial engineers call job preparation. For instance, before the Bullard can grind a rear stator case for an engine, artisans must tape all orifices to prevent metal particles from entering the case during grinding. Additionally, splines of rubber tubing are placed between rotor case vanes to snub or prevent bending during grinding. (Snubbing operations are also done for rotor blades prior to lathe grinding operations). Fixtures are required to mount the component onto the machine. Once these are located and installed on the machine, the components can then be moved to the work station and mounted on the fixture. Artisans must also locate special parts, clamps, tools and technical information required to commence

setup operations. Presently, artisans complete all these operations (job preparation) after the machine is shut down. Job preparation often consumes 75% of the time to complete many setups. Finishing operations, like deburring, also lengthen setup times since artisans perform most finishing operations when the machine is idle.

Artisans do prepare some operations in advance of changeover. The most illustrative example involves preparing an engine rotor for mounting on a lathe. Since the rotor is conical in shape, the larger end of the rotor is affixed to the lathe using a fixture plate. To attach the smaller end of the rotor to the spindle, a freezeplug is fitted inside the rotor, expanding as it thaws to room temperature (a 30-minute process). After expansion, the freezeplug provides a secure anchorage point to the lathe's spindle. Generally, artisans complete this process as an OED operation.

In summary, artisans do attempt to complete operations in advance of changeover whenever they can. Still, their inability to leave machines unattended while processing components prevent them from achieving this goal in most cases. The necessity of finishing operations further compounds reaching this goal. The use of setup teams or idle workers to complete operations in advance of changeover could alleviate wasted productive time (machine idle time), thereby increasing

productivity. If completed as OED operations, machine idle time and setup times could be drastically reduced.

(2) *Use of Intermediary Jigs*

Centering operations within the Machine Shop are laborious and time consuming operations. Most jobs within the Machine Shop require two centering operations: the fixture requires centering on the machine and the component requires centering on a fixture. In some jobs, the component does not require centering on the fixture, but fixtures (or smaller components not requiring fixtures) always require centering on the machine. In many cases, idle workers or setup teams could employ intermediary jigs to setup one job as another is being processed. One foreseeable difficulty involves the cost of producing or buying additional fixtures. Although artisans can design and produce fixtures within the shop, the approval process from engineers is often lengthy and difficult. Nevertheless, centering operations are one of the most time consuming tasks within the Machine Shop since most tolerances provide for only a 1/1000" leeway and batch processing is seldom practical. The need to shim components and fixtures warped from use when attaching to machines further complicates centering tasks. Still, the concept of using intermediary jigs is feasible and can significantly reduce times required for most centering operations.

(3) *Function Standardization*

Fixtures in the Machine Shop come in many shapes and sizes, some capable of multiple uses (usually designed and produced within the shop) while others are specifically designed by the manufacturer (like General Electric) for a particular component. Attempts to standardize clamping heights for all fixtures or for components to fixtures would not be a sensible solution in light of the variability of fixture and component size and shape. Yet, function standardization of the manner in which fixtures are attached to machines and in which components are affixed to fixtures is possible.

Some fixtures attach to machines by bolting the external edge of the fixture in place; others attach to machines by bolting the internal edge or some internal point of the fixture in place. If the affixing bolts of the fixture are covered by the component once it is attached to the fixture, then the use of intermediary jigs is not possible. For example, if the component were attached to and centered on a fixture (jig plate) as an OED operation while another component is being processed, then attaching the combined fixture and component (intermediary jig) to the machine's faceplate depends on whether the affixing bolts of the fixture are still accessible. If the component sits on top of the fixture's affixing bolts, then attachment of the intermediary jig to the machine may not be possible. In this case, the

intermediary jig would require dismantling to allow the fixture to first be attached to the machine's faceplate. By standardizing fixture attachment to the external edge of the fixture to allow continuous access (while avoiding the possibility of being covered by the component), artisans could simplify setups and capitalize on the use of intermediary jigs.

Attachment of components to fixtures also vary because of the numerous shapes and sizes of components and fixtures. Some components are clamped to fixtures while others are bolted. Still, such shortcomings are resolvable with innovative clamping procedures and one-turn or one-motion applications. These considerations will be addressed later in this thesis.

b. Streamlining Internal and External Setups

(1) Streamlining OED Operations

The streamlining of numerous OED operations within both shops is possible. First, tools are often located in near proximity of work stations, but rarely are they laid out or organized for the following setup before commencing changeover. Only one artisan in the Fuel Control work center during this research proved to be the exception. Second, the Machine Shop stored fixtures in multi-tiered racks within the work center. Fixtures were generally stored in disarray, with no apparent system to account for their location. Third,

transportation of components and fixtures to work stations within the Machine Shop was accomplished by using floor-level dollies or forklifts. Larger parts and fixtures required two persons to move them safely to the work station. A forklift assisted the movement when available. However, acquiring a forklift was often a time-consuming process.

As previously discussed, setup teams or idle workers could better organize tools and fixtures prior to changeovers. The use of visual controls can also aid in streamlining OED operations. Tool templates specifying tools required for a particular setup and better organization of fixtures using color coding can eliminate the need for the "search and work" mentality. Control charts listing the availability and location of fixtures and organizing larger fixtures on pallets positioned in storage racks to allow easy forklift access could also assist in streamlining OED operations. The need for forklifts could also be eliminated by installing a jib crane near a centralized fixture storage location to aid in the movement of large fixtures to and from storage racks. The hoist on the crane could have a pendent controller that any operator could use (much like the hoists located near machines).

c. Streamlining IED Operations

(1) Parallel Functions

The Machine Shop and the Fuel Control work centers employ one operator for each machine and test bench respectively. In many instances, small work spaces and the lack of additional employees limit the practicality of parallel operations. Fuel Control test benches and most of the machines in the Machine Shop do not physically allow two-sided access and, in some cases, do not have ample room to permit a two-person (side-by-side) setup operation. Fortunately, most lathes within the Machine Shop do allow two-sided access to machines and are excellent candidates for employing parallel operations. For instance, when mounting an engine compressor rotor on a lathe in preparation for blade grinding operations, the artisan must use the machine's jib crane to hoist the rotor onto the lathe, attach the rotor, and indicate (measure and level) both the fore and aft portions of the rotor before processing commences. This ensures the artisan grinds the proper blade angle and depth when the lathe is turning. With training and practice, it is possible to employ two persons to shorten mounting time, thereby decreasing machine idle time and setup time. Tasks for each person can be derived by analyzing the setup worksheets generated in stage 1 of SMED, which separates IED and OFD operations. Industrial engineers and operators should focus on these IED operations to devise

a complementary division of work in order to implement parallel operations.

(2) *Functional Clamps*

Several examples of functional clamping exist within the Machine Shop. Some fixtures employ a single-turn motion to clamp components to the fixture. Most often seen were the clamp method and U-slot method illustrated in Chapter III and depicted in Figures 13 and 14 respectively. Other fixtures use single-turn or one-motion clamping when attached to machine face plates and simultaneously center the fixture. In addition, most lathes can use a universal chuck (fixture) which automatically centers a workpiece on the drive head of the lathe.

Still, many fixtures lack such capabilities. Artisans applied numerous turns of several bolts for each fixture either when attaching the fixture to a machine face plate or when attaching a component to a fixture. Many artisans felt the need to use numerous turns of a bolt on fixtures or components for several reasons. Since components varied in shape and size, so did their available attachment surface. Many components had outer flanges (usually of variable size) with holes normally used to bolt the component to the engine. Artisans attached such components to fixtures using these holes and numerous bolts. Some artisans felt that numerous turns were required to ensure bolts did not sheer



Figure 13. Fixture With Single-Turn Clamping

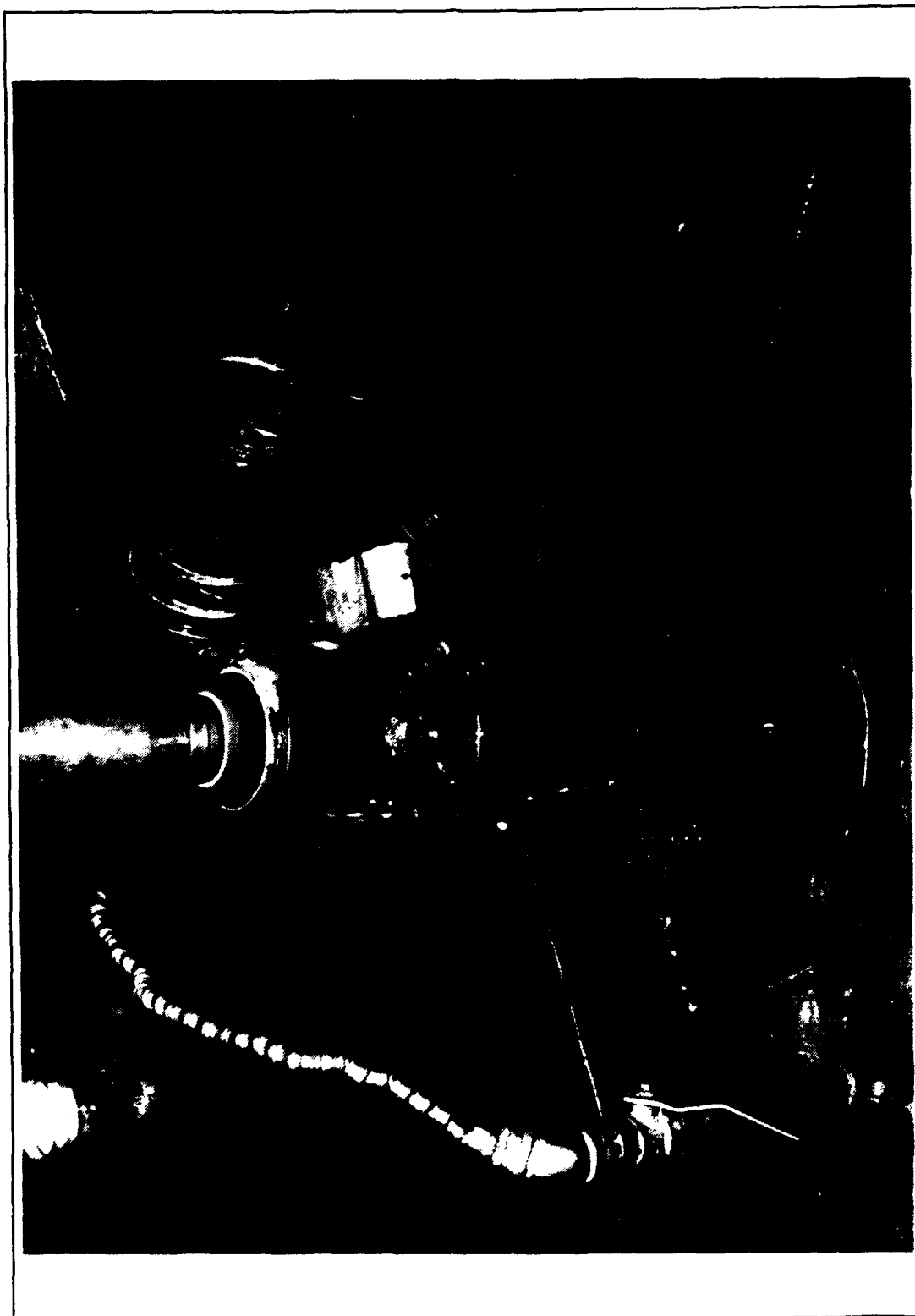


Figure 14. Fixture Employing U-Slot Clamping

when in the fixture and to prevent slippage of the component during processing operations.

The Fuel Control work center could also improve setup operations using functional clamps. As discussed earlier, each engine type has dedicated fuel control test benches. Before fuel control testing can commence, artisans must attach numerous hoses to the fuel control unit. Figure 15 shows the F404 fuel control unit. Presently, the hoses require several turns to connect them to the fuel control units. The number of hoses varies with the type fuel control unit tested. Setup time reductions are possible by replacing the standard screw-type coupling with a high-pressure, quick-release coupling. Adaptive plugs for quick-release couplings could be attached to the fuel control units as an OED operation, thereby converting an IED operation to an OED operation. Additionally, quick-release couplings reduce the number of tools required, simplifying the setup.

(3) *Elimination of Adjustments*

Adjustments plague the Machine Shop much more than the Fuel Control area. In the Fuel Control work center, artisans mount the fuel control unit to the test bench as a setup, free from adjustments. Artisans then complete test bench adjustments (regulating fluid flow) without interrupting testing operations. Yet, in the Machine Shop, this author contends that adjustments will never be totally eliminated.

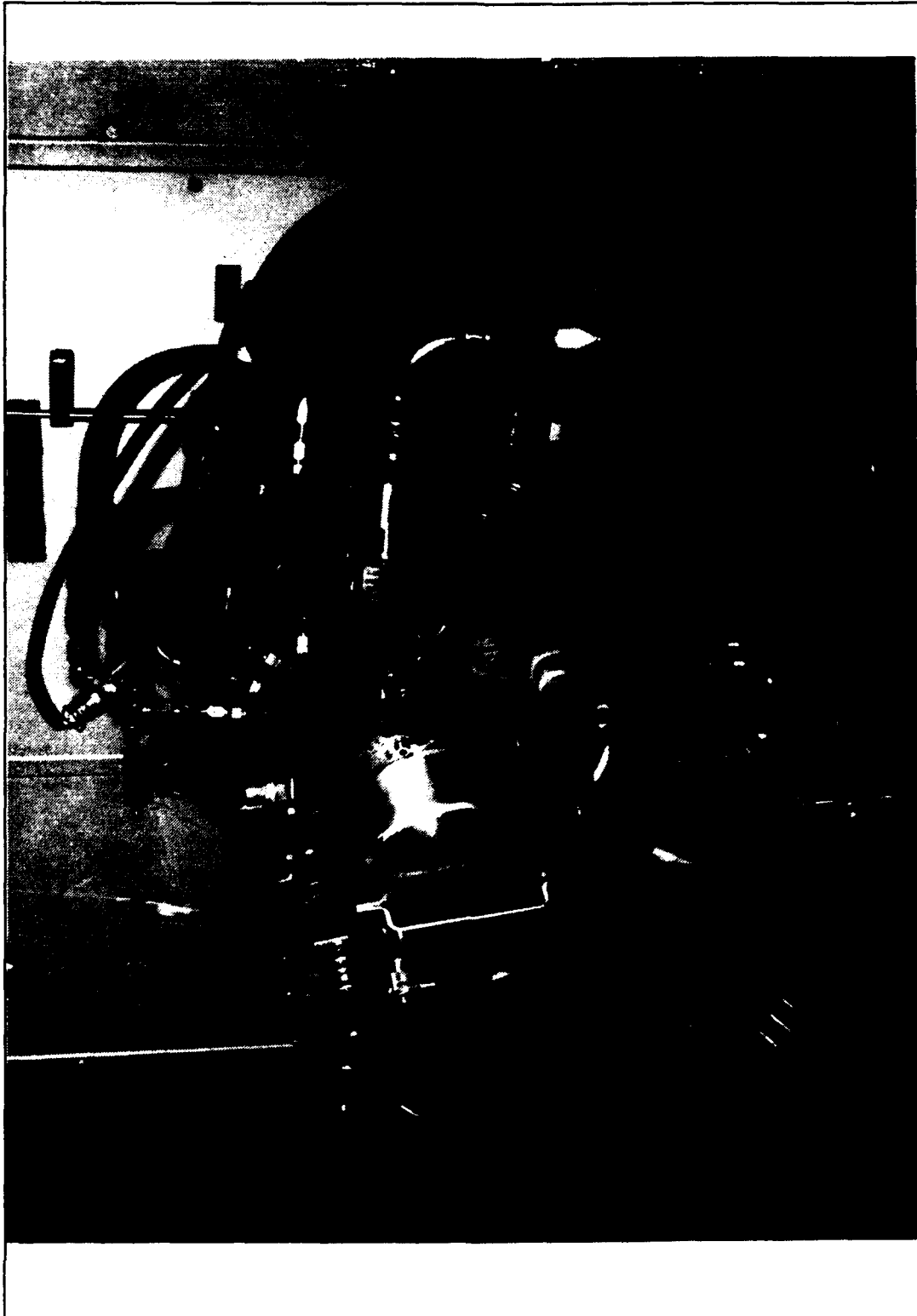


Figure 15. The F404 Fuel Control Unit

Jet engines can expand and contract four inches between operation and shut down. Although engines return to their original size when restored to ambient temperature conditions, component wear may vary, depending on how and how long the engine was operated. This explains why like engine components entering the Machine Shop can vary significantly in shape and size, accounting for single batch sizes. Therefore, each component requires treatment as a separate setup, even if batching were possible. Exceeding tolerances of $1/1000$ " during machine processing can result in scrapped parts costing \$100,000 or more and delayed engine availability to the Fleet. Additionally, fixtures not made of the proper material and not heat-treated tend to warp after continued use. Generally, this tends to occur when fixtures are fabricated locally. Cost, non-availability of the proper material (to include lengthy timeframes needed to acquire), and lengthy approval processes to make or buy fixtures are often the most prevalent reasons for this problem. Artisans must use shims in such cases to level the fixture prior to beginning processing operations. These are a few examples denying the total elimination of adjustments.

Artisans can, however, minimize adjustments in many cases. By using imaginary center lines or reference points, artisans can remove some of the intuition presently used in centering operations. For instance, the Bullard (see Figure 8) has a large, rotating table upon which artisans

attach fixtures and components (if a fixture is not needed). Several radially-cut inverted T-grooves in the table provide a means of clamping fixtures and components to the table. Also, the machine manufacturer etched concentric rings into the table's surface at one inch intervals to allow better "eyeball-centering" of circular-based fixtures and components. Present centering procedures involve using the machine's jib crane to hoist the fixture or component from its dolly to the table, "eyeball-centering" them using the concentric rings, and finalizing centering using a dial indicator before commencing grinding operations. Artisans could reduce adjustments for common jobs by etching more (and closer) concentric rings on the table, being careful not to etch the rings so close as to confuse centering operations. Using adjustable, quick-release stops placed in the inverted T-grooves at predetermined points (using the etched circles) could act as limiting edges for fixtures and components during setup operations, simplifying the initial setup by removing some "eyeball centering".

Other machines, like the vertical grinder, have similar type tables, but no concentric circles are etched into the surface. The same suggestions discussed above could also apply. Lathe operations could also use the above procedures on some setups. Further, lathes could employ fixtures that attach to machine faceplates by employing an outward chucking action or a one-motion clamping techniques

instead of bolting the fixture to the faceplate. Fixtures of this type are available in industry today and can significantly reduce or eliminate fixture centering adjustments. [Ref. 3]

D. BARRIERS TO SMED IMPLEMENTATION

Several barriers within the Fuel Control and the Machine Shop work centers challenge the effective implementation of the SMED philosophy. Most importantly, SMED requires cultural acceptance at all levels within the command structure. Presently, the Naval Aviation Depot uses a beneficial suggestion program for workers to voice concerns or suggestions and a gain-sharing program to monetarily reward workers for cost-saving innovations. Several workers interviewed, however, feel gain-sharing is not an effective rewards program. Shallow incentives complicated by a bureaucracy which continually scrutinizes the dollar value of change can have a deflating effect on innovation at the shop floor level. This should be a management concern.

This author also observed that some artisans were not receptive to SMED because productivity improvements are often associated with job phase-out. This belief is far from the truth. In fact, reduced setup time opens the door for more productive time. Economic changes force personnel lay-offs, not productivity improvements. Other artisans believe cost inhibits many of the innovative ideas discussed above.

Certainly, cost is a prime consideration within the Department of Defense today, but many setup reductions require minimal cost. Training personnel is often expensive. However, SMED is simplistic in design, requiring perhaps one day of instruction to reorient artisan's approach to reducing setup times.

With every assumed organizational barrier, a counter argument exists in SMED's favor. Still, any organization's culture possesses deep roots. These roots present the biggest barrier to SMED's implementation. Change cannot take place unless management is enthusiastic about it. No operator is going to do it unless he gets guidance and support from management.

E. SUMMARY

Setup time reductions and more simple setups can be expected within the Fuel Control and Machine Shop work centers with the implementation of the SMED philosophy. The examples presented above provide only a few possibilities. As shown in this chapter, SMED is a simple, viable, and innovative approach to setup time reductions in a repair/rebuild facility. The primary barriers to SMED confronting the Machine Shop and Fuel Control work centers are a total commitment to a revolutionary way of approaching setups and cultural change at all levels of the command. Overcoming such barriers is the key to SMED's successful implementation.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This thesis examined the importance of setup time considerations in a repair/rebuild environment. The Machine Shop and the Fuel Control work centers located at the Power Plant facility, Naval Aviation Depot, North Island, were the focal points of this analysis.

First, an overview of the Power Plant's current material flow and management within a production context was examined with an emphasis on shop floor procedures that impacted most on system lead time. Next, traditional approaches to setup operations and the benefits of reducing setup times were examined. The conceptual stages of Single-Minute-Exchange-of-Die (SMED) were presented as a revolutionary approach for achieving significant setup time reductions. Finally, the applicability of SMED to the Machine Shop and the Fuel Control work centers was illustrated, providing potential solutions where applicable.

B. CONCLUSIONS

This author has shown that long lead times plague the Power Plant facility as a result of scheduling and shop floor management problems. Additionally, further reduction of batches is not possible (being one in most cases) to reduce

system lead time and increase throughput. Each component processed requires a separate setup operation.

Setup time reduction on machines provides a solution to accommodate this very small batch production. By reducing setup times on machines, lead time variability for the system can also be reduced. Although the system benefits achieved through decreased lead time variability on bottleneck work centers are more pronounced, setup time reductions on critical work centers are also valuable. Such process improvements can yield cost savings, improved quality, reduced WIP inventories, flexibility of operations, increased productivity, and improved efficiency.

SMED is a revolutionary way to approach setup time reductions today. Understanding SMED is simple and realistic and the benefits derived from SMED's successful implementation are innumerable. Setup times can be reduced up to 90% in many cases utilizing the SMED program. Setup operations that once took hours can now be accomplished under 10 minutes. As shown in this thesis, SMED is applicable to the Power Plant facility. Wherever setups are required, SMED offers a solution for reducing changeover times. The major organizational requirements for successful implementation of SMED are a total commitment and cultural change at all echelons within the work force.

C. RECOMMENDATIONS

1. Implement SMED On Critical Work Stations To Reduce Setup Times

Shingo recommends that SMED be applied throughout a facility on every machine. To begin this process at the Power Plant Facility the author recommends that the SMED program be initially applied to only the critical Machine Shop and Fuel Control work stations.

Although this author has provided some recommendations to reduce setup times in the previous chapter (like intermediary jigs, functional clamping, and function standardization), the number of alternatives are only limited by the innovativeness of the people involved with setup time reductions. Commercial products designed to reduce setup times on machines are available and are used in industry today; many at relatively minimal cost. Numerous ideas already exist on the NADEP shop floor but are discouraged due to lack of incentives and bureaucracy [Ref. 9].

To assure the proper implementation of SMED, the Power Plant facility should implement a training program for artisans, foremen, and managers to establish a common understanding of SMED and its benefits. Such a training program could be developed and initiated with minimal cost by the industrial engineering department or by Naval Postgraduate School faculty interested in research within this area. Having

management attend professional seminars would also be worthwhile. Employee involvement, training, and guidance on what to look for and how to improve the process is a necessity for SMED implementation. Finally, discussions with employees of companies who have successfully implemented SMED for machine shop operations would be helpful to operators and supervisors of the Naval Aviation Depot.

2. Redefine Setup Time Terminology

Presently, the Power Plant Facility's definition of setup time captures only a portion of the true setup time for a machine. First, the setup time established within this job shop pertains to a particular process, not a specific machine. Second, the industrial engineers currently advocate separating setup time into two subcomponents: setup time and preparation time. Although the Industrial Engineering Department is beginning to capture setup times for processes on MDR's for time management purposes, the setup times recorded are suspect, since preparation times are often included as a part of process time. This author recommends that setup time should be defined as the changeover time that starts when the last good product is completed by a machine and ends when the first good product of the next job is produced consistently, without further adjustments.

Further, as Shingo advocates, Power Plant Facility personnel should distinguish setup time by differentiating

between internal setups and external setups. By adopting Shingo's terminology of Internal Exchange of Die (IED) operations and Outside Exchange of Die (OED) operations, setups are more easily understood by workers and managers at all levels. A better understanding of what setup time is can reduce the present subjective or ad hoc approach to identifying setup time and can increase worker capabilities to produce innovative ways to initiate setup time reductions. Establishing an environment where everyone understands what setups are comprised of is essential before achieving exceptional setup time reductions.

3. Implement Setup Teams

The Power Plant Facility should develop setup teams for critical work centers. Since, in most cases, operators cannot leave machines unattended during processing operations, setup teams could aid immensely in converting IED setup operations to OED setup operations. Machine down time could, therefore, be significantly reduced, increasing productivity and effectiveness of operations. Setup teams could be composed of dedicated workers assigned to setups or of idle artisans waiting for their next transfer batch. This author feels that the use of setup teams to complete operations in advance of changeovers or to complete parallel functions when possible could reduce current setup operations by at least 50% by

alleviating the need to continue "search and find" techniques for parts, tools, and technical information during setups.

4. Recommendations For Future Work

During the course of this analysis, several potential areas for future research became evident. The following research questions are provided and encouraged for subsequent analysis:

1. What production control computer management systems are available today that might assist facilities like NADEP to better analyze and determine critical path, bottleneck, and capacity-constrained work stations? Is MRP II the solution?
2. Can a methodology or model be developed to aid NADEP in determining present work station capacity? If so, is this methodology or model compatible with current MRP II efforts?
3. Can a cost-benefit analysis ascertain the value of setup time reductions on NADEP operations?
4. Group Technology (GT) layout "allocates dissimilar machines into cells to work on products that have similar shapes and processing requirements." [Ref. 5:p. 376] One benefit of GT layout is a reduced number of setups on each machine, which may aid SMED's implementation. Is Group Technology (GT) layout a viable means to reducing setups at NADEP and/or a complement to SMED's implementation?

APPENDIX

GLOSSARY

Adjustment	The subsequent calibration or modification required following the initial setting.
Bottleneck	A machine or person whose capacity is less than the demand placed upon it, limiting system throughput.
Capacity-Constrained Work Station	A machine or person whose utilization is close to the demand placed upon it, and could become a bottleneck if not scheduled carefully.
Critical Work Station	A machine or person located on a critical path. These work stations may or may not be bottleneck or capacity-constrained.
Critical Path	The longest time path through a system. The critical path identifies the elements that actually constrain the total time for the system.
Excess production	Production of goods or services before they are demanded.
FE Component Program	Fleet Engine Component Program. An induction program for components at the Power Plant Facility. This is different from engine inductions since only the component enters the repair program from the Fleet.
Function Standardization	Standardizing only those parts whose functions are necessary from the standpoint of setup operations. These functions include gripping, dimensioning, centering, securing, expelling, and maintaining loads.
IED Operations	Internal-Exchange-of-Die Operations. Setup operations that can only be done when the machine is stopped.

Intermediary Jigs	Standard size jig plates or fixtures used by operators to attach similar workpieces. As the operator processes one workpiece, the next workpiece can be prepared and readied in advance of operations for processing.
Job Shop Manufacturing	A classification of production processes that involves the production of discrete units in small batches. These batches need not follow the same sequence of operations, as do repetitive manufacturing. A job shop's departments are organized around particular machines or operations.
Lead Time	The interval between the time an order is released from the planning system to the execution system and the time the order is completed and sent to inventory.
OED Operation	Outside-Exchange-of-Die. Setup operations that can be done while the machine is running.
Parallel Functions	Utilizing more than one worker to complete setup operations.
Process Batch	A product lot size large or small enough to be processed in a given time period, normally composed of setup time and processing time. A cost associated with a processing batch is the setup cost.
Repetitive Manufacturing	A classification of production involving the high-volume production of a discrete item that is either standard in form or made from standard options in a process with sequence of operations common to most (i.e., assembly line).
RFI	Ready For Issue. The engine or components are repaired and available for service.

Setup Time	The changeover time that starts when the last product is completed by a machine and ends when the next product's first good unit is produced consistently, without further adjustments.
SMED	Single-Minute-Exchange-of-Die. A program of reducing setup times to under 10 minutes.
Throughput	The rate at which products are delivered by the system and sold to customers. This is more than just the rate of production.
Transfer Batch	Refers to the amount of the process batch moved between processes, and should never be greater than the process batch. Costs associated with transfer batches may involve a tradeoff between transportation costs and inventory costs.
WIP	Work in Process Inventory.

LIST OF REFERENCES

1. Shingo, Shigeo, *A Revolution in Manufacturing: The SMED System*, Productivity Inc., 1985.
2. Boyer, T. G., *Analysis of the Production Planning and Inventory Control System Used by NADEP, North Island, for the Repair of the T-64 Series Engine*, Masters Thesis, Naval Postgraduate School, Monterey, California, June 1988.
3. Interviews with Industrial Engineers and Artisans at the Power Plant facility, NADEP, North Island, 26 February-2 March 1990.
4. Melnyk, S. A. and Carter, P. L., *Production Activity Control*, Dow Jones-Irwin, 1987, pp. 159-176.
5. Chase, R. B. and Aquilano, N. J., *Production and Operations Management: A Life Cycle Approach*, 5th ed., Irwin, 1989.
6. Goldratt, E. M. and Fox, R. E., *The Race*, Croton-on-Hudson, New York, North River Press, 1986.
7. Lundrigan, R., "What is This Thing Called OPT?" *Production and Inventory Management*, Second Quarter, 1986, pp. 2-11.
8. Severson, D., "The SMED System for Reducing Changeover Times: An Exciting Catalyst for Company-wide Improvement and Profits," *Production and Inventory Management*, Vol. 8, No. 10, October 1988, pp. 10, 15-16.
9. Johansen, P. and McGuire, K. J., "A Lesson in SMED With Shigeo Shingo," *Industrial Engineering*, Vol. 8, No. 10, October 1986, pp. 26-28, 30, 32-33.
10. Robbins, R. M., "Quick Changeovers--Fast Paybacks," *Manufacturing Systems*, March 1989, pp. 53-55.
11. Trietsch, D., *Polynomial Transfer Lot Sizing Techniques For Batch Processing on Consecutive Machines*, Naval Postgraduate School Report NPS-54-89-011, September 1989, pp. 1-5.

12. Stickler, M. J. and Buker, D. W., "SMED Equals Higher Productivity," presented at the American Production and Inventory Control Society, 29th Annual International Conference Proceedings, 1986, pp. 381-385.
13. Gritzmacher, K. J., "Visual Control Tools: A Hidden Productivity Factor?" *National Productivity Review*, Autumn, 1987, pp. 314-323.
14. Shingo, Shigeo, *The SMED System, Parts I and II*, Productivity Press, 1987.

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